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VAN. H. MANNING, DIRECTOR

THE SAND TEST

FOR DETERMINING THE STRENGTH OF DETONATORS

BY

C. G. STORM AND W. C. COPE

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THE SAND TEST FOR DETERMINING THE STRENGTH OF DETONATORS.

By C. G. Storm and W. C. Cope.

INTRODUCTION.

In connection with the investigations of explosives conducted by the Bureau of Mines, it is important that suitable tests be devised for determining the relative strengths of detonators, or the comparative ability of different grades or types of detonators to bring about the complete detonation of blasting explosives. The term "detonator" is used in the publications of the Bureau of Mines to designate what the miner calls a "blasting cap"—a copper capsule containing a small quantity of some detonating compound that is ignited by a fuse. The term "electric detonator" is applied to a blasting cap that is similar except for being ignited by means of a small wire which is heated to incandescence or fused by the passage of an electric current.

It is generally admitted that the detonation of an explosive charge by means of an initial detonator is the result of the combined action of the mechanical shock produced by the explosion of the detonator and the heat produced thereby. The chief requisite of an initial detonator is that it shall produce an intense local action in the form of a blow caused by the release of a large quantity of energy in a very short period of time.

Fulminate of mercury may be considered as a typical example of an initial detonating agent. It is the best known of this class of explosives, and, either alone or mixed with other substances, it forms the charge of most of the commercial detonators or electric detonators used in mining and other engineering operations in this country.

THEORIES REGARDING THE ACTION OF DETONATORS.

Many theories have been offered to explain the action of detonators or primary explosives, and to show the reason for the superiority of mercury fulminate as a detonator as compared with other explosives that, seemingly, should be just as effective in bringing about the detonation of dynamite and similar explosives. For example, Abel [a] advanced the theory that the action of the primary explosive, or

[a] Abel, F., Études sur les propriétés des corps explosibles: Compt. rend., t. 78, 1874, p. 1228.

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detonating agent, on the secondary explosive is due to a wave synchronism or sympathetic molecular vibration between the priming substance and the secondary explosive, similar to the sympathetic vibrations in stringed instruments, in this manner accounting for the fact that even small quantities of mercury fulminate can bring about the detonation of other explosives, whereas such explosives as nitrogen chloride, nitrogen iodide, and diazobenzene nitrate, which are regarded as more violent than mercury fulminate, accomplish the same results only when used in much larger quantities. Thus, 0.32 gram of mercury fulminate caused the detonation of guncotton, whereas more than 10 times as much nitrogen chloride (3.25 grams) was required for the same purpose, and 6.5 grams of nitrogen iodide failed to cause detonation of the guncotton.

Wöhler [a] set aside Abel's theory of wave synchronism, and attributed the effects of mercury fulminate to the production, by its explosion, of an enormous momentary pressure, the pressure being due to the kinetic energy of the gas molecules and therefore dependent primarily on the rate of detonation and density of the fulminate, and secondarily on the gas volume and heat evolved.

Nobel, who first used mercury fulminate as a detonator in 1864, states in his patent specifications [b] regarding mercury fulminate: "The principle of its action consists invariably in the production of a very intense shock or pressure." [c]

Gody [d] states that the pressure exerted by the explosion of fulminate of mercury is estimated at 31,000 kilograms per square centimeter at its point of contact.

Berthelot [e] gives for pressures exerted the following values, expressed in kilograms per square centimeter: Mercury fulminate, 28,750; nitroglycerine, 12,376; nitrocellulose, 9,825. He attributes the initiating effect of the fulminate to the sudden development of the enormous pressure indicated. He also notes that there can be little if any dissociation of the products of explosion of mercury fulminate, all of the heat liberated by the reaction being effective in expanding the gases of explosion. Berthelot has sought to prove that mechanical shock does not, as a rule, cause explosion directly, but indirectly through the heat produced.

At any rate, it seems evident that the explosion of mercury fulminate results in an intense local action in the form of an enormous sudden pressure or blow, owing to the rapid transformation of a solid of high density into a relatively large gas volume at a high temperature. It also seems evident that the intense local action is

[a] Wöhler, L., and Matter, O., Beitrag zur Wirkung der Initialzündung von Sprengstoffen: Ztschr. gesamte Schiess- und Sprengstoffwesen, vol. 2, 1907, pp. 181, 203, 244, 265.

[b] English Patent 1345, May 7, 1867.

[c] Daniel, J., Dictionnaire des matières explosives, 1902, p. 193.

[d] Gody, Leon, Traité théorique et pratique des matières explosives, 1907, p. 279.

[e] Berthelot, M., Explosives and their power, 1892, p. 469 (translation by Hake and Macnab).

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responsible for the initiation of the explosion wave in the charge of dynamite or other explosive, with its production of chemical, thermal, and mechanical effects.[a]

DIRECT AND INDIRECT METHODS OF TESTING DETONATORS.

The measurement of the mechanical effects of this local action forms the basis of all of the co-called direct methods of testing the strength or efficiency of detonators. Indirect methods of testing detonators depend on the mechanical effects produced by explosives whose detonation is brought about by the detonators in question.

A former publication of the Bureau of Mines [b] presents a discussion of the commonly used tests, both direct and indirect, for determining the relative efficiency of detonators, and the results there set forth indicate that "the methods previously used for the direct determination of the relative strength of detonators were not satisfactory or accurate." The tests referred to were as follows: (1) Lead-block tests, in which the detonators were fired in holes drilled in lead blocks, and the resulting expansion of each hole measured; (2) tests by explosion of detonating fuse by influence, in which the limiting distance at which no explosion of a piece of trinitrotoluene detonating fuse (Cordeau detonant) resulted from the influence of the explosion of the detonator; and (3) tests by depression of lead plates, the detonators being placed on end in the center of one-half inch lead plates and the depression resulting on firing the detonator being measured.

An additional test by a direct method, designated the nail test,[c] is discussed. The test depends on the angle at which a 4-inch wire finishing nail is bent when a detonator is fired in close proximity to it. The test is rather simple, inexpensive, and quickly made, and the average result of a sufficient number of tests gives an approximate comparison of strengths of different detonators.

In all of these direct methods of testing detonators, however, the variation in results is considerably greater than the variation in weight of charge of the detonators, and it is apparent that a simple and reliable direct method of determining the strength of detonators is still much to be desired.

As regards indirect methods of testing detonators, it is obvious that the best criterion by which to compare the relative efficiency of detonators is to compare their ability to bring about the complete detonation of insensitive explosives, or to produce the greatest mechanical effects from such explosives. Such methods of testing demand that the different cartridges of insensitive explosives used in the comparative tests be uniform in every respect, a condition difficult to meet,

[a] Berthelot, M., Loc. cit.; see also Hall, Clarence, and Howell, S. P., Investigations of detonators and electric detonators: Bull. 59, Bureau of Mines, 1913, pp. 9–10.

[b] Hall, Clarence, and Howell, S. P., Investigations of detonators and electric detonators: Bull. 59, Bureau of Mines, 1913, 73 pp.

[c] Hall, Clarence, and Howell, S. P., Op. cit., pp. 25–26.

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especially in commercial explosives that have become insensitive through age. Furthermore, indirect methods of testing require too much time or too expensive apparatus, or both, to be of practical use in routine tests for determining the relative strength of commercial detonators.

REQUIREMENTS FOR A SATISFACTORY TEST OF DETONATORS.

In practice, every detonator tested is embedded in the explosive to be detonated. It is therefore unreasonable to expect that a test depending on the effects of the firing of detonators under unlike conditions of confinement should give reliable information as to the efficiency of the detonators in producing the detonation of blasting explosives.

The lead-plate tests, explosion-by-influence tests, nail test, and others, all depend on the mechanical effects produced by unconfined detonators placed in certain definite positions relative to the material to be acted on. For example, the maximum distance at which a detonator will cause the explosion of a cartridge of dynamite varies according as to whether the detonator is laid at right angles or parallel to the cartridge.

In the lead-block test the detonator is closely surrounded by the lead upon which it acts, but the results of comparisons obtained with this test fail to show that the test is a reliable one for determining the relative efficiencies of detonators.

The sand test described in this bulletin is so conducted that the detonator is embedded in a material upon which the "smashing" effect, which appears to be the essential characteristic of an initial detonator, is free to exert itself, thereby producing a result that may be accurately measured. When the detonator is thus surrounded, the material to be acted on is subjected to all of the influences exerted by the explosion of the detonator—the violent blow, the pressure of the gases of combustion, the heat liberated, the characteristic wave or vibrations set up by the explosion, etc. The material on which the detonator performs its work is, in turn, inclosed within a solid, unyielding cavity, just as the primer cartridge of an explosive in which a detonator is placed in practice is confined by the walls of the drill hole.

It is necessary, however, that the effects measured in the sand test should be shown to be comparable to the effects produced by the detonator in practice. It is the opinion of the writers that the new test described in this report more nearly fulfills this requirement than any other direct method of testing, and that the results of the tests presented here confirm this opinion.

PRELIMINARY INVESTIGATION OF SAND TEST.

In 1910, W. O. Snelling, then explosives chemist of the Bureau of Mines, devised a direct method for testing the strength of detonators, which depended on the extent to which a hard, brittle material of

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uniform granulation was pulverized by the explosion of the detonator charge. The detonator was placed in a suitable bomb, which was then partly filled with a given weighed quantity of ordinary, clean, dry sand of uniform granulation (20 to 40 mesh), care being taken that the detonator was approximately in the center of the mass of sand. The detonator was then fired and the degree of the resulting disintegration or pulverization of the sand was determined by removing the sand from the bomb and sifting it through a series of standard sieves. The total quantity of sand passing through the 40-mesh sieve varied to a marked degree with detonators of different commercial grades, but was remarkably uniform for detonators of the same grade. Thus, tests of a number of detonators from a given lot showed that the percentage variation in the weight of sand pulverized was no greater than the percentage variation in weight of charge.

In the preliminary work a total of about 40 tests were made of different samples of detonators and electric detonators varying in grade from No. 3, containing a charge of approximately 0.5 gram, to No. 6, containing about 1 gram of the usual mixture of mercury fulminate and potassium chlorate. The results obtained indicated that the method offered a convenient and accurate means of determining the relative strength of detonators,[a] in spite of the fact that as it measured only the physical effects produced by the detonator, it appeared to be subject to most of the objections that have been advanced concerning the various direct methods of testing before mentioned.

SYSTEMATIC DEVELOPMENT OF SAND TEST.

In 1913 the writers began a systematic investigation of the sand test for determining the strength of detonators, and believe that the results presented herewith justify the acceptance of this method of testing detonators as a reliable means of determining the relative efficiency of the different grades of commercial detonators.

SCOPE OF WORK.

The preliminary work before mentioned has been continued and extended in the following respects:

1. A large number of detonators and electric detonators of the various commercial grades have been tested, and the results have been compared with the average weights of charge in these various grades.

2. A series of tests have been made of weighed charges of mercury fulminate and of mixtures containing 90 per cent of mercury fulminate and 10 per cent of potassium chlorate, and of other mixtures containing 80 per cent of mercury fulminate and 20 per cent of potassium chlorate, in order to determine the relative crushing

[a] Brief mention of the work was made in a paper on "The Energy of Explosives," by W. O. Snelling: Proc. Eng. Soc. Western Pa., vol. 28, November, 1912, p. 673.

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effects of these three initial detonating materials as shown by the sand test.

3. The comparative crushing effects have been shown to be in agreement with the relative efficiencies of these three initial detonating materials in causing the detonation of various insensitive explosive nitrosubstitution compounds.

4. The test has been applied to a comparison of the relative strengths of various nitrosubstitution compounds when used, together with a suitable priming charge, in the so-called "reinforced" detonators.

5. A limited study has been made of the effects of variations that may be produced in "reinforced" detonators, such as variations in charging pressure, in size of crystals of nitrocompound, in purity of nitrocompound, and the like.

GRADE OF SAND USED.

The sand used in the preliminary work was ordinary river sand, carefully dried and screened through 20-mesh and 40-mesh sieves, the sand caught on the 20-mesh and passing through the 40-mesh sieve being rejected, and the material caught on the 40-mesh sieve being used in the tests. The results of tests with this were closely uniform, but it was considered advisable to find a material that would not require careful preliminary preparation, and could be obtained by others wishing to make practical use of the method.

The material finally selected was a pure, clean grade of quartz sand designated as "Ottawa standard sand," furnished by the Ottawa Silica Co., of Ottawa, Ill. This sand is practically free from particles coarser than 30-mesh, and entirely passes through a 20-mesh sieve. It is approximately pure quartz, containing about 99.90 per cent of SiO_2, and different lots of it can reasonably be expected to give the same results with detonators containing equal weights of the same composition. In fact, three different 100-pound lots of this sand, used in the bureau's laboratory, gave closely-agreeing results

APPARATUS AND METHOD OF OPERATION.

The apparatus used and the general method followed in making the tests described in this report are practically identical with the apparatus and method used in the preliminary work mentioned.

DESCRIPTION OF APPARATUS.

The apparatus (Pl. I) consists of a small steel bomb approximately 21 centimeters ($8\frac{1}{4}$ inches) long and 9 centimeters ($3\frac{1}{2}$ inches) in diameter, with a cylindrical chamber or cavity 15 centimeters (6 inches) deep and 3.1 centimeters ($1\frac{7}{32}$ inches) in diameter. Two covers are provided of the same diameter as the bomb, each being 2.2 centimeters ($\frac{7}{8}$ inch) thick at the edge and about 2.4 centimeters ($\frac{15}{16}$ inch) thick at the center. The thicker part of the center

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provides a slight projection which just fits in the top of the cylindrical cavity of the bomb. One of the covers has a central hole $\frac{15}{64}$ inch in diameter, which permits the passage through it of a piece of ordinary black-powder fuse. This cover is used when ordinary det-

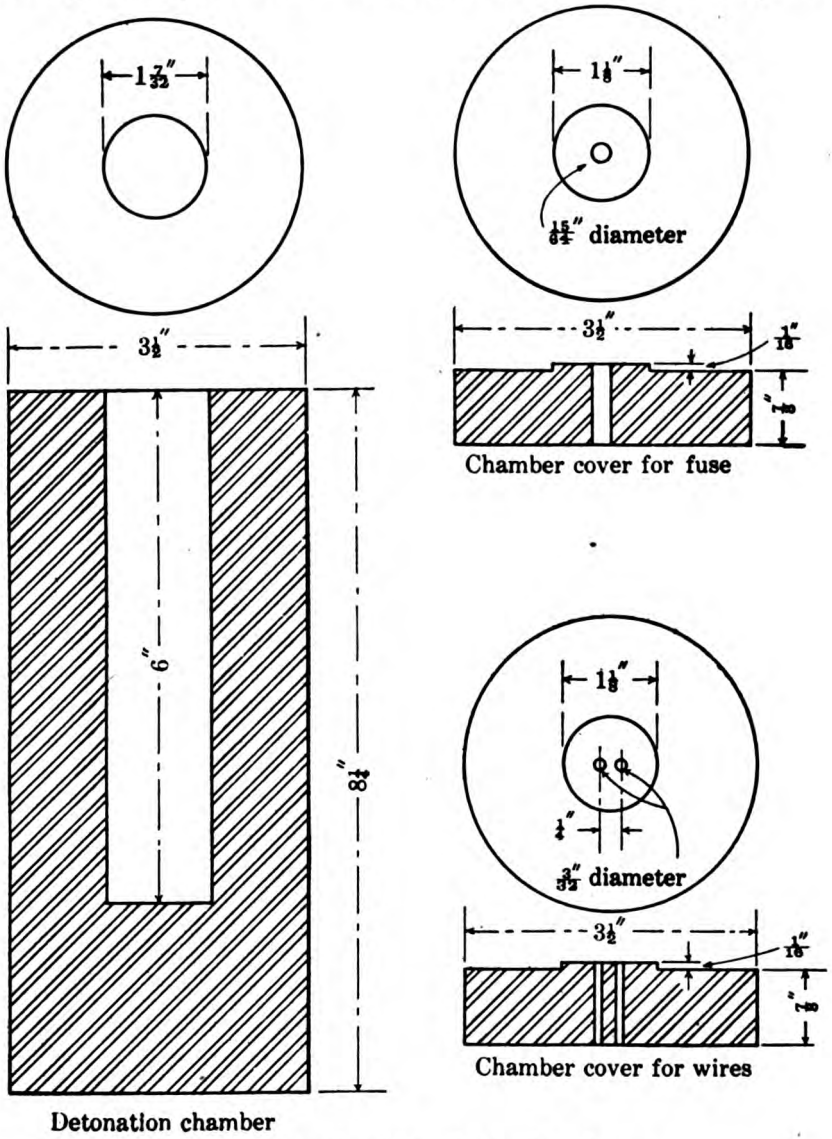

FIGURE 1.—Cross sections of detonating chamber and covers.

onators are being tested. The other cover is used in testing electric detonators and has near its center two small holes of such diameter as to allow the legs of an electric detonator to fit snugly. The bomb and its covers were made from a piece of steel shafting of suitable size. Details of its construction are shown in Plate I and figure 1.

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A suitable clamping device, as shown in the illustrations, retains the cover in position and prevents loss of sand when the detonator is fired.

PROCEDURE IN TEST.

PLACING OF DETONATOR.

The method of procedure is the same for testing either electric detonators or ordinary detonators. The detonator is fired in approximately the center of a mass of 100 grams of the standard sand placed within the cavity of the bomb, and the extent to which the sand is pulverized by the detonation is then measured by screening tests. In testing electric detonators the legs are passed through the two small holes in one of the covers of the bomb, and in testing blasting caps a short length of fuse, crimped to the cap, is passed through the larger hole in the other cover.

Forty grams of the sand is weighed on a small pulp balance or other convenient form of scale that will weigh to 0.01 gram. This sand is poured into the cavity of the bomb, the bomb struck sharply two or three times with a light hammer in order that the sand may be uniformly packed, and the detonator is then carefully inserted so that it rests on top of the sand and in, as nearly as possible, the exact center of the cavity, being held upright in this position by means of its fuse or wires.

Sixty grams more of the sand (making a total of 100 grams) is poured around the detonator in the bomb and the bomb tapped with a hammer as before. The proper cover for the bomb is next put in place, the wires or fuse being passed through the holes in the cover without disturbing the position of the detonator or electric detonator in the center of the mass of sand. The bomb is placed within the clamping device and the cover held tightly in position by screwing down the two hexagonal nuts on the upright iron rods.

SCREENING THE SAND.

The sound produced by the explosion of the detonator within the bomb is faint, resembling a sharp "click," such as is produced by striking together two pieces of metal. After the explosion the cover of the bomb is removed and the sand emptied onto a large sheet of glazed paper, such part as may adhere within the cavity being removed by means of a suitable scraper and brush. The electric-detonator legs or the charred fuse, together with any large fragments of the copper shell, are rejected after any adhering sand has been removed from them, and the entire charge of sand is carefully sifted through a nest of five brass-wire sieves of 30, 40, 60, 80, and 100 mesh to the linear inch.

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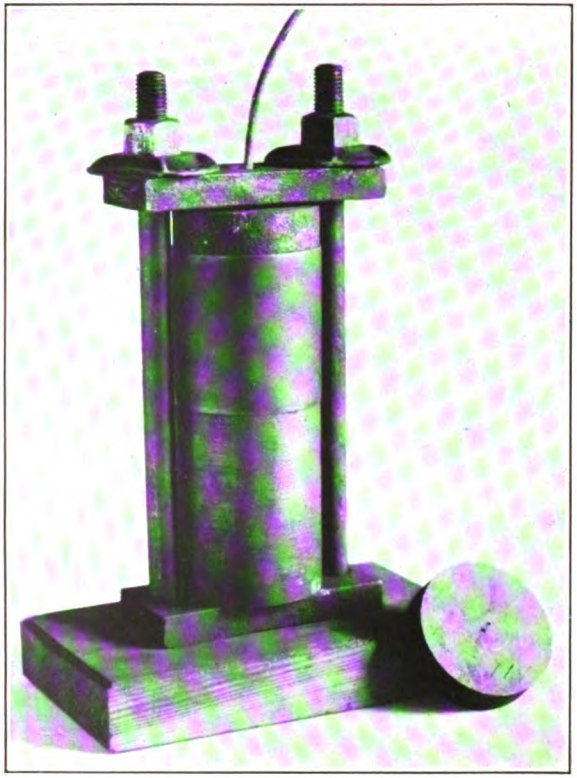
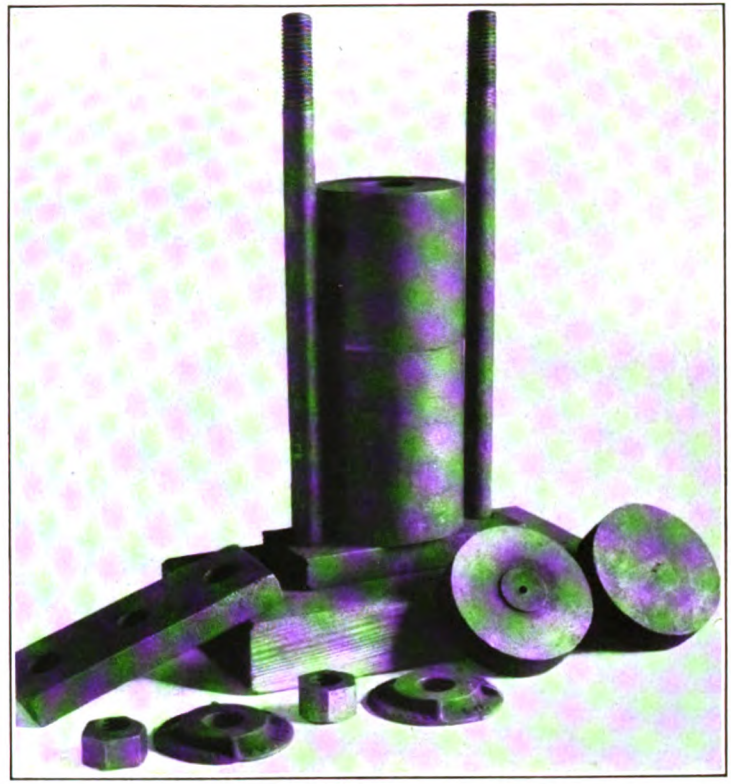


A. BOMB ASSEMBLED FOR MAKING SAND TEST.



B. DETAILS OF BOMB.

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The sifting is done with both the brass bottom and the cover in place on the nest of sieves, and is facilitated by tapping lightly on the sides of the sieves with the hand or jolting the bottom against the table top. The sand should not be rubbed with the hand, as such treatment would force through the sieve particles that would otherwise remain on the sieve. Any hard, compact lumps of finely powdered sand are crushed between the fingers. Such lumps are usually found adhering tightly to the fragments of the copper shell of the detonator.

After the screening is complete the separate fractions of the sand remaining in each sieve and in the bottom tray are emptied onto small sheets of glazed paper, transferred separately to a weighing scoop, and weighed. The sum of all of the fractions should equal 100 grams plus the weights of the fragments of the copper shell left with the sand.

PRECAUTIONARY MEASURES.

When detonators of greater strength than No. 5 grade are to be tested, the explosion of the detonator may blow the fuse out of the hole in the cover, and throw some of the sand out of the bomb. Such loss may be avoided by some suitable means of holding the burned fuse in place during the explosion of the detonator. A convenient method for accomplishing this result is to slip over the fuse a short length of soft black-rubber tubing (about 0.5 inch long and of such inside diameter that it fits snugly on the fuse), and to adjust it at such a point on the fuse that when the detonator is in proper position in the center of the mass of sand, the upper end of the rubber tube will be at about the level of the top of the bomb. Thus, when the cover is placed in position with the fuse passing out through the opening, the end of the rubber tube is in contact with the lower side of the cover. When the detonator explodes, any tendency of the fuse to be blown out of the hole is checked by the rubber tube. With this precaution the loss of sand is negligible. No such precaution is necessary in testing electric detonators, as the wires are not blown out of the small holes.

TESTS OF STANDARD GRADES OF DETONATORS AND ELECTRIC DETONATORS.

STANDARD CHARGES.

Following are the weights of charges that have been regarded as standard charges for detonators and electric detonators containing the usual mercury fulminate and potassium chlorate.

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Standard weight of charge in different grades of detonators.[a]

Grade No.	Weight of charge.	
	Grams.	Grains.
1	0.30	4.6
2	.40	6.2
3	.54	8.3
4	.65	10.0
5	.80	12.3
6	1.00	15.4
6½	1.25	19.2
7	1.50	23.1
8	2.00	30.9

a Hall, Clarence, and Howell, S. P., Investigations of detonators and electric detonators: Bull. 59, Bureau of Mines, 1913, p. 14.

In order to determine whether the sand test of detonators would differentiate between the various grades of commercial detonators made in this country, tests were made of samples of each grade on hand at the bureau's Pittsburgh experiment station, and for comparison the results of the sand test, the average weights of charge, and composition of the various samples were determined. The results of these tests are shown in the tables following.

TEST OF DETONATORS CONTAINING APPROXIMATELY 90 PER CENT OF MERCURY FULMINATE AND 10 PER CENT OF POTASSIUM CHLORATE.

NO. 3 DETONATORS.

Twenty detonators were selected from a box of No. 3 detonators (M1296). Ten of these were tested by the sand test. The remaining 10 were used in determining the "average weight of charge" and in the analysis of the "composition" contained in the detonators. The results follow:

Results of sand tests of No. 3 detonators, sample M1296.

Test No.	Weight of sand finer than 30-mesh caught on—				Weight of sand through 100-mesh.	Total weight of sand finer than 30-mesh.
	40-mesh.	60-mesh.	80-mesh.	100-mesh.		
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
1	3.47	4.10	2.26	1.57	11.48	22.88
2	3.66	3.97	2.50	1.64	10.61	22.38
3	4.11	3.87	2.46	1.39	10.26	22.09
4	3.45	3.84	2.24	1.63	10.66	21.82
5	3.67	3.75	2.27	1.56	9.94	21.19
6	3.07	4.15	2.38	1.50	10.27	21.37
7	2.79	4.06	2.30	1.47	11.81	22.43
8	2.94	4.23	2.42	1.60	12.44	23.63
9	3.00	4.00	2.34	1.48	10.75	21.57
10	2.77	3.91	2.22	1.46	10.62	20.98
Average	3.29	3.99	2.34	1.53	10.88	22.03
Maximum variation from average						a 1.60

a 7.26 per cent of average.

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Weight and composition of charge in No. 3 detonators, sample M1296.

Test No.	Weight of charge.	Composition of charge.	
		Mercury fulminate.	Potassium chlorate.
	Grams.	*Per cent.*	*Per cent.*
11	0.5128		
12	.5270		
13	.5299	89.56	10.44
14	.4871		
15	.5054		
16	.4617		
17	.4742		
18	.4873	89.41	10.59
19	.4533		
20	.5148		
Average	.4953	89.49	10.51
Maximum variation from average	[a] .0420		

[a] 8.5 per cent of average.

The maximum variation from the average total weight of sand pulverized finer than the original granulation (30-mesh) was 1.60 grams, or 7.26 per cent of the average, whereas the corresponding maximum variation from the average weight of charge of the detonators was 8.5 per cent of the average. There was, therefore, an excellent agreement between the average weight of sand pulverized and the average charge in the detonators.

NO. 4 DETONATORS.

Five detonators from a box of No. 4 detonators (sample A) were tested by the sand test, and the weight of charge determined on six from the same box, the charge from two of these being analyzed.

Results of sand tests of No. 4 detonators, sample A.

Test No.	Weight of sand finer than 30-mesh caught on—				Weight of sand through 100-mesh.	Total weight of sand finer than 30-mesh.
	40-mesh.	60-mesh.	80-mesh.	100-mesh.		
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
1	3.89	4.57	2.82	1.80	15.00	28.08
2	3.62	4.56	2.68	1.61	13.91	26.38
3	3.67	4.55	2.65	1.87	14.76	27.50
4	3.64	4.79	2.64	1.91	14.70	27.68
5	3.94	4.88	2.85	1.65	14.21	27.53
Average	3.75	4.67	2.73	1.77	14.52	27.44
Maximum variation from average						[a] 1.06

[a] 3.8 per cent of average.

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Weight and composition of charge in No. 4 detonators, sample A.

Test No.	Weight of charge.	Composition of charge.	
		Mercury fulminate.	Potassium chlorate.
	Grams.	*Per cent.*	*Per cent.*
6	0.6775		
7	.6347	89.22	10.78
8	.6138		
9	.6285		
10	.6430	89.52	10.48
11	.6170		
Average	.6358	89.37	10.63
Maximum variation from average	[a] .0417	.....	.....

[a] 6.5 per cent of average.

In this lot of No. 4 detonators, the maximum variation from the average of the five sand tests made was only 3.8 per cent, whereas the maximum variation in the weights of charge of six detonators was 6.5 per cent of the average weight of charge.

NO. 5 DETONATORS AND ELECTRIC DETONATORS.

The tests of No. 5 detonators and electric detonators included tests of four lots containing the usual mixture of approximately 90 per cent mercury fulminate and 10 per cent potassium chlorate, and two lots of electric detonators containing the same mixture, with a small priming charge of long-fiber guncotton. A limited supply of some of the lots made it impracticable to determine the weight of charge in more than three detonators. The results were as follows:

Results of sand tests of No. 5 detonators, sample No. 178.

Test No.	Weight of sand finer than 30-mesh caught on—				Weight of sand through 100-mesh.	Total weight of sand finer than 30-mesh.
	40-mesh.	60-mesh.	80-mesh.	100-mesh.		
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
1	4.26	5.35	2.74	1.97	14.13	28.45
2	4.47	5.52	3.01	2.04	15.06	30.10
3	4.16	5.12	2.74	1.89	14.09	28.00
4	4.30	4.68	3.01	2.14	14.50	28.63
5	3.76	5.31	3.10	1.58	14.96	28.71
6	4.94	5.47	2.91	2.05	14.25	29.62
7	4.31	5.15	2.96	2.07	14.51	29.00
8	4.39	4.91	2.91	2.14	14.59	28.94
9	4.40	5.08	3.02	1.84	13.89	28.23
10	4.23	5.00	3.08	1.76	14.59	28.66
Average	4.32	5.16	2.95	1.95	14.46	28.83
Maximum variation from average	.....	.....	.....	.....	.....	[a] 1.27

[a] 4.4 per cent of average.

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Weight and composition of charge in No. 5 detonators, sample No. 178.

Test No.	Weight of charge.	Composition of charge.	
		Mercury fulminate.	Potassium chlorate.
	Grams.	*Per cent.*	*Per cent.*
11	0.6847		
12	.6858		
13	.7005	88.48	11.52
14	.6944		
15	.6853		
16	.7505		
17	.6900		
18	.7117	88.28	11.72
19	.6710		
20	.6928		
Average	.6967	88.38	11.62
Maximum variation from average	[a].0541	.....	.....

[a] 7.8 per cent of average.

Results of sand tests of No. 5 detonators, sample 178a.

Test No.	Weight of sand finer than 30-mesh caught on—				Weight of sand through 100-mesh.	Total weight of sand finer than 30-mesh.
	40-mesh.	60-mesh.	80-mesh.	100-mesh.		
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
1	3.40	5.01	2.60	1.59	14.72	27.32
2	3.33	4.79	2.81	1.80	15.18	27.91
3	3.73	4.88	2.72	1.61	15.17	28.11
4	3.55	4.93	2.58	1.72	15.50	28.28
5	3.91	5.10	2.59	1.53	16.77	29.90
6	4.10	5.24	2.86	1.92	16.90	31.02
Average	3.67	4.99	2.69	1.69	15.71	28.75
Maximum variation from average	.....	.....	.....	.....	.....	[a] 2.27

[a] 7.9 per cent of average.

Weight and composition of charge of No. 5 detonators, sample 178a.

Test No.	Weight of charge.	Composition of charge.	
		Mercury fulminate.	Potassium chlorate.
	Grams.	*Per cent.*	*Per cent.*
7	0.6960		
8	.6990	90.02	9.98
9	.7530		
Average	.7160	90.02	9.98
Maximum variation from average	[a].0370	.....	.....

[a] 5.2 per cent of average.

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Results of sand tests of No. 5 detonators, sample 178b.

Test No.	Weight of sand finer than 30-mesh caught on—				Weight of sand through 100-mesh.	Total weight of sand finer than 30-mesh.
	40-mesh.	60-mesh.	80-mesh.	100-mesh.		
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
1	3.63	4.89	3.18	2.05	16.07	29.82
2	3.62	5.25	3.17	2.15	16.45	30.64
3	3.43	4.94	3.10	2.14	15.94	29.55
4	3.55	5.11	3.06	2.14	15.71	29.57
5	3.76	5.02	3.14	2.24	16.17	30.33
6	3.60	5.05	3.01	2.09	16.53	30.28
Average	3.60	5.04	3.11	2.13	16.15	30.03
Maximum variation from average						0.61

[a] 2 per cent of average.

Weight and composition of charge of No. 5 detonators, sample 178b.

Test No.	Weight of charge.	Composition of charge.	
		Mercury fulminate.	Potassium chlorate.
	Grams.	*Per cent.*	*Per cent.*
7	0.8055	90.85	9.15
8	.7712		
9	.7278		
Average	.7682	90.85	9.15
Maximum variation from average	[a].0404		

[a] 5.3 per cent of average.

Results of sand tests of No. 5 detonators, sample B.

Test No.	Weight of sand finer than 30-mesh caught on—				Weight of sand through 100-mesh.	Total weight of sand finer than 30-mesh.
	40-mesh.	60-mesh.	80-mesh.	100-mesh.		
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
1	3.99	5.52	3.17	2.31	17.11	32.10
2	4.51	4.62	3.35	1.59	17.60	31.67
3	4.46	5.24	3.17	1.86	18.64	33.37
4	3.93	5.07	3.39	2.13	17.91	32.43
5	4.12	5.36	3.50	2.43	18.21	33.62
Average	4.20	5.16	3.32	2.06	17.89	32.63
Maximum variation from average						[a].99

[a] 3 per cent of average.

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Weight and composition of charge of No. 5 detonators, sample B.

Test No.	Weight of charge.	Composition of charge.	
		Mercury fulminate.	Potassium chlorate.
	Grams.	*Per cent.*	*Per cent.*
6	0.7200	89.61	10.39
7	.7018		
8	.7015		
9	.7225	89.59	10.41
10	.7600		
11	.7120		
Average	.7205	89.60	10.40
Maximum variation from average	[a].0395		

[a] 5.5 per cent of average.

Results of sand tests of No. 5 electric detonators, sample M34–C.

Test No.	Weight of sand finer than 30-mesh caught on—				Weight of sand through 100-mesh.	Total weight of sand finer than 30-mesh.
	40-mesh.	60-mesh.	80-mesh.	100-mesh.		
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
1	4.72	5.90	3.37	2.09	16.40	32.48
2	5.00	5.51	3.45	2.16	15.32	31.44
3	4.61	5.60	3.59	2.13	16.82	32.75
4	4.78	5.83	3.58	2.38	16.50	33.07
5	4.98	5.88	3.49	2.22	16.78	33.25
Average	4.82	5.74	3.49	2.19	16.36	32.60
Maximum variation from average						[a] 1.16

[a] 3.6 per cent of average.

Weight and composition of charge of No. 5 electric detonators, sample M34–C.

Test No.	Weight of detonating charge.	Weight of priming charge (gun-cotton).	Composition of detonating charge.	
			Mercury fulminate.	Potassium chlorate.
	Grams.	*Grams.*	*Per cent.*	*Per cent.*
1	0.6928	0.0220	90.09	9.91
2	.6927	.0395		
3	.6840	.0260		
4	.6727	.0430		
5	.7150	.0250	90.09	9.91
6	.6859	.0292		
7	.6781	.0166		
8	.6907	.0315	90.10	9.90
9	.6801	.0315		
10	.7227	.0405		
Average	.6915	.0302	90.09	9.91
Maximum variation from average weight of total charge	[a].0415			

[a] 5.8 per cent of average.

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Results of sand tests of No. 5 electric detonators, sample M1015.

Test No.	Weight of sand finer than 30-mesh caught on—				Weight of sand through 100-mesh.	Total weight of sand finer than 30-mesh.
	40-mesh.	60-mesh.	80-mesh.	100-mesh.		
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
1	3.88	6.17	3.47	2.71	18.40	34.63
2	3.90	5.29	2.95	2.24	17.47	31.85
3	3.48	5.57	3.28	2.02	17.91	32.26
4	3.43	5.21	3.05	1.88	17.67	31.24
5	3.68	5.56	3.16	2.17	18.15	32.72
Average	3.68	5.56	3.18	2.20	17.92	32.54
Maximum variation from average						[a] 2.09

[a] 6.4 per cent of average.

Weight and composition of charge of No. 5 electric detonators, sample M1015.

Test No.	Weight of detonating charge.	Weight of priming charge (guncotton).	Composition of detonating charge.	
			Mercury fulminate.	Potassium chlorate.
	Grams.	*Grams.*	*Per cent.*	*Per cent.*
6	0.7100	0.0240		
7	.6595	.0140		
8	.6747	.0280		
9	.6933	.0270		
Average	.6849	.0230	90.13	9.87
Maximum variation from average weight of total charge	[a] .0261			

[a] 3.7 per cent of average.

Following is a tabulation summarizing the results of the tests of various grades of No. 5 commercial detonators containing approximately 90 per cent of mercury fulminate and 10 per cent of potassium chlorate:

Summary of results of tests of No. 5 detonators and electric detonators containing approximately 90 per cent mercury fulminate and 10 per cent potassium chlorate.

Sample No.	Average weight of charge.	Average total weight of sand finer than 30-mesh.	Maximum variation from average.	
			Weight of charge.	Total weight of sand finer than 30-mesh.
	Grams.	*Grams.*	*Per cent.*	*Per cent.*
178	0.6967	28.83	7.8	4.4
178[a]	.7160	28.75	5.2	7.9
178[b]	.7682	30.03	5.3	2.0
B	.7205	32.63	5.5	3.0
M34-C	[a] .7217	32.60	5.8	3.6
M1015	[b] .7079	32.54	3.7	6.4
Average	.7220	30.90	5.5	4.6

[a] Includes 0.0302 gram of guncotton priming charge.
[b] Includes 0.0230 gram of guncotton priming charge.

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The results tabulated above show that (1) for an average weight of charge of 0.7220 gram 30.90 grams of the standard sand was pulverized to a finer granulation than 30-mesh, and this can therefore be taken as the average sand-test value for the No. 5 detonators tested; (2) the maximum percentage variation among the sand-test values is no greater than that among the weights of charge.

NO. 6 DETONATORS AND ELECTRIC DETONATORS.

The tests of No. 6 detonators and electric detonators included tests of three lots of ordinary detonators and three lots of electric detonators, all containing approximately 90 per cent of mercury fulminate and 10 per cent of potassium chlorate. The results of the tests are shown in the following tables:

Results of sand tests of No. 6 detonators, sample C.

Test No.	Weight of sand finer than 30-mesh caught on—				Weight of sand through 100-mesh.	Total weight of sand finer than 30-mesh.
	40-mesh.	60-mesh.	80-mesh.	100-mesh.		
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
1	4.76	5.93	3.40	2.39	20.49	36.97
2	4.38	5.88	3.47	2.55	20.05	36.33
3	4.85	5.96	3.69	2.43	20.21	37.14
4	4.65	5.68	3.31	2.59	20.96	37.19
5	4.88	5.58	3.54	2.57	19.38	33.95
Average	4.70	5.81	3.48	2.51	20.22	36.72
Maximum variation from average						[a] 2.77

[a] 7.5 per cent of average.

Weight and composition of charge of No. 6 detonators, sample C.

Test No.	Weight of charge.	Composition of charge.	
		Mercury fulminate.	Potassium chlorate.
	Grams.	*Per cent.*	*Per cent.*
6	1.0050	89.75	10.25
7	.9255		
8	.9715		
9	.9873	89.84	10.16
10	.9725		
11	.9777		
Average	.9732	89.80	10.20
Maximum variation from average	[a] .0477		

[a] 4.9 per cent of average.

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Results of sand tests of No. 6 detonators, sample M1451.

Test No.	Weight of sand finer than 30-mesh caught on—				Weight of sand through 100-mesh.	Total weight of sand finer than 30-mesh.
	40-mesh.	60-mesh.	80-mesh.	100-mesh.		
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
1	3.94	6.04	3.52	2.36	20.53	36.39
2	4.52	6.05	3.30	2.34	20.28	36.49
3	4.08	5.75	3.39	2.44	20.81	36.47
4	4.01	5.60	3.20	2.32	19.34	34.47
5	3.76	5.54	3.27	2.22	19.29	34.08
Average	4.06	5.80	3.34	2.33	20.05	35.58
Maximum variation from average						[a] 1.50

[a] 4.2 per cent of average.

Weight and composition of charge of No. 6 detonators, sample M1451.

Test No.	Weight of charge.	Composition of charge.	
		Mercury fulminate.	Potassium chlorate.
	Grams.	*Per cent.*	*Per cent.*
6	0.9522	89.90	10.10
7	.9617		
8	.9505		
9	.8600	90.00	10.00
10	.9655		
11	.9715		
Average	.9136	89.95	10.05
Maximum variation from average	[a].0836		

[a] 8.8 per cent of average.

Results of sand tests of No. 6 detonators, sample M1530.

Test No.	Weight of sand finer than 30-mesh caught on—				Weight of sand through 100-mesh.	Total weight of sand finer than 30-mesh.
	40-mesh.	60-mesh.	80-mesh.	100-mesh.		
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
1	3.73	5.85	3.47	2.21	20.31	35.57
2	3.71	5.75	3.43	2.62	20.51	36.02
3	3.77	5.58	3.36	2.35	20.01	35.07
4	4.27	6.09	3.53	2.24	19.70	35.83
5	4.00	5.98	3.58	2.56	20.80	36.92
Average	3.90	5.85	3.47	2.39	20.27	35.88
Maximum variation from average						[a] 1.04

[a] 2.9 per cent of average.

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Weight and composition of charge of No. 6 detonators, sample M1530.

Test No.	Weight of charge.	Composition of charge.	
		Mercury fulminate.	Potassium chlorate.
	Grams.	*Per cent.*	*Per cent.*
6	1.0060	89.37	10.63
7	.9003		
8	.9747		
9	.9615		
Average	.9607	89.37	10.63
Maximum variation from average	[a].0603	.....	.....

[a] 6.3 per cent of average weight.

Results of sand tests of No. 6 electric detonators, sample M1588–A.

Test No.	Weight of sand finer than 30-mesh caught on—				Weight of sand through 100-mesh.	Total weight of sand finer than 30-mesh.
	40-mesh.	60-mesh.	80-mesh.	100-mesh.		
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
1	4.63	5.49	3.30	1.81	18.94	34.17
2	4.53	5.62	3.06	1.96	20.04	35.21
3	4.98	5.83	3.18	2.29	19.92	36.20
4	4.65	5.46	3.24	1.93	19.21	34.49
5	4.49	5.64	3.18	2.57	19.63	35.51
6	3.91	5.85	3.66	2.53	20.10	36.05
Average	4.53	5.65	3.27	2.18	19.64	35.27
Maximum variation from average	.....	.....	.....	.....	.....	[a]1.10

[a] 3.1 per cent of average.

Weight and composition of charge of No. 6 electric detonators, sample M1588–A.

Test No.	Weight of charge.	Composition of charge.	
		Mercury fulminate.	Potassium chlorate.
	Grams.	*Per cent.*	*Per cent.*
7	0.9836	89.75	10.25
8	.9874		
9	.9873		
10	.9851		
11	.9807	89.68	10.32
12	.9714	89.42	10.58
13	1.0127	89.25	10.75
14	1.0131	89.48	10.52
15	.9837		
16	1.0025		
Average	.9910	89.52	10.48
Maximum variation from average	[a].0221	.....	.....

[a] 2.2 per cent of average.

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Results of sand tests of No. 6 electric detonators, sample M1480.

Test No.	Weight of sand finer than 30-mesh caught on—				Weight of sand through 100-mesh.	Total weight of sand finer than 30-mesh.
	40-mesh.	60-mesh.	80-mesh.	100-mesh.		
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
1	5.08	5.80	3.44	2.38	21.91	38.61
2	5.65	5.69	3.40	2.48	21.23	38.45
3	5.31	5.38	3.44	2.20	21.71	38.04
Average	5.35	5.62	3.43	2.35	21.62	38.37
Maximum variation from average						[a] .24

[a] 0.6 per cent of average.

Weight and composition of charge of No. 6 electric detonators, sample M1480.

Test No.	Weight of charge.	Composition of charge.	
		Mercury fulminate.	Potassium chlorate.
	Grams.	*Per cent.*	*Per cent.*
4	1.0203	88.70	11.30
5	1.0516		
Average	1.0359	88.70	11.30
Maximum variation from average	[a] .0157		

[a] 1.5 per cent of average.

Results of sand tests of No. 6 electric detonators, sample M1588.

Test No.	Weight of sand finer than 30-mesh caught on—				Weight of sand through 100-mesh.	Total weight of sand finer than 30-mesh.
	40-mesh.	60-mesh.	80-mesh.	100-mesh.		
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
1	4.87	5.59	3.41	2.27	21.24	37.38
2	5.11	5.11	3.36	2.28	21.50	37.36
3	5.07	5.67	3.51	2.59	21.03	37.87
4	5.15	5.65	3.48	2.32	22.10	38.70
Average	5.04	5.50	3.44	2.38	21.47	37.83
Maximum variation from average						[a] .87

[a] 2.3 per cent of average.

Weight and composition of charge of No. 6 electric detonators, sample M1588.

Test No.	Weight of charge.	Composition of charge.	
		Mercury fulminate.	Potassium chlorate.
	Grams.	*Per cent.*	*Per cent.*
5	1.0131	89.48	10.52
6	.9867		
7	1.0025		
Average	1.0008	89.48	10.52
Maximum variation from average	[a] .0141		

[a] 1.4 per cent of average.

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Summary of results obtained with No. 6 detonators and electric detonators containing approximately 90 per cent mercury fulminate and 10 per cent potassium chlorate.

Sample.	Average weight of charge.	Average total weight of sand finer than 30-mesh after sand test.	Maximum variation from average.	
			Weight of charge.	Weight of sand finer than 30-mesh after sand test.
	Grams.	*Grams.*	*Per cent.*	*Per cent.*
C	0.9732	36.72	4.9	7.5
M1451	.9436	35.58	8.8	4.2
M1530	9606	35.88	6.3	2.9
M1588A	.9910	35.27	2.2	3.1
M1480	1.0359	38.37	1.5	.6
M1588	1.0008	37.83	1.4	2.3
Average	.9842	36.61	4.2	3.4

The results of the tests of the No. 6 detonators and electric detonators show an average weight of charge of 0.9842 gram and an average weight of 36.61 grams of the standard sand pulverized to a finer granulation than 30-mesh after the sand test.

Again, in these tests the average percentage of maximum variations in the weights of charge are slightly greater than that of the weights of sand pulverized finer than 30-mesh.

NO. 7 DETONATORS AND ELECTRIC DETONATORS.

Three lots of No. 7 detonators and electric detonators were tested, one lot consisting of ordinary detonators, the other two being electric detonators. All contained 90 per cent of mercury fulminate and 10 per cent of potassium chlorate. The results of the tests are given in the following tables:

Results of sand test of No. 7 detonators, sample M54.

Test No.	Weight of sand finer than 30-mesh caught on—				Weight of sand through 100-mesh.	Total weight of sand finer than 30-mesh.
	40-mesh.	60-mesh.	80-mesh.	100-mesh.		
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
1	5.11	7.19	4.77	2.80	27.98	47.85
2	4.69	7.00	4.37	3.39	27.14	46.59
3	4.31	7.11	4.38	3.18	28.74	47.72
4	5.02	7.11	4.49	3.23	26.73	46.58
5	4.56	7.22	3.81	2.68	27.98	46.25
Average	4.74	7.09	4.36	3.06	27.71	46.96
Maximum variation from average						*a* .89

a 2 per cent of average.

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Weight and composition of charge of No. 7 detonators, sample M54.

Test No.	Weight of charge.	Composition of charge.	
		Mercury fulminate.	Potassium chlorate.
	Grams.	*Per cent.*	*Per cent.*
6	1.4500	.....	.....
7	1.4440	89.71	10.29
8	1.4914	.....	.....
9	1.4147	.....	.....
10	1.4482	.....	.....
11	1.4750	.....	.....
Average	1.4554	89.71	10.29
Maximum variation from average	[a].0407	.....	.....

[a] 2.8 per cent of average.

Results of sand tests of No. 7 electric detonators, sample M1595.

Test No.	Weight of sand finer than 30-mesh caught on—				Weight of sand through 100-mesh.	Total weight of sand finer than 30-mesh.
	40-mesh.	60-mesh.	80-mesh.	100-mesh.		
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
1	6.38	7.32	3.83	2.89	25.50	45.92
2	6.28	7.07	4.79	2.63	25.78	46.55
3	5.63	6.38	4.18	3.47	24.43	44.09
4	6.13	7.20	3.82	3.04	26.04	46.23
5	5.62	7.48	5.00	2.51	24.40	45.01
6	5.44	7.14	4.08	2.95	26.42	46.03
7	6.02	6.91	3.89	2.62	27.44	46.88
8	5.66	7.52	4.26	2.68	27.60	47.72
9	6.17	6.86	4.50	1.98	27.63	47.14
10	6.45	6.73	4.52	2.30	27.75	47.75
Average	5.98	7.06	4.29	2.70	26.30	46.33
Maximum variation from average	.....	.....	.....	.....	.....	[a]2.24

[a] 4.8 per cent of average.

Weight and composition of charge of No. 7 electric detonators, sample M1595.

Test No.	Weight of charge.	Weight of guncotton primer.	Composition of charge.	
			Mercury fulminate.	Potassium chlorate.
	Grams.	*Grams.*	*Per cent.*	*Per cent.*
11	1.4035	0.0200	.....	.....
12	1.3956	.0220	89.85	10.15
13	1.4625	.0180	.....	.....
14	1.4326	.0100	.....	.....
15	1.3789	.0150	.....	.....
16	1.4584	.0380	.....	.....
17	1.3736	.0140	89.69	10.31
18	1.4070	.0400	.....	.....
19	1.3978	.0130	.....	.....
20	1.4118	.0460	.....	.....
Average	1.4122	.0230	89.77	10.23
Maximum variation from average weight of total charge	[a].0612	.....	.....	.....

[a] 4.2 per cent of total charge.

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Results of sand test of No. 7 electric detonators, sample M1523.

Test No.	Weight of sand finer than 30-mesh caught on—				Weight of sand through 100-mesh.	Total weight of sand finer than 30-mesh.
	40-mesh.	60-mesh.	80-mesh.	100-mesh.		
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
1	6.36	7.65	4.71	2.95	25.59	47.26
2	5.87	7.44	4.48	2.51	29.02	49.32
3	6.26	6.77	4.39	2.85	27.07	47.34
4	5.81	6.85	4.28	2.48	29.03	48.81
Average	6.07	7.18	4.46	2.79	27.68	48.18
Maximum variation from average						[a] 1.14

[a] 2.4 per cent of average.

Weight and composition of charge of No. 7 electric detonators, M1523.

Test No.	Weight of detonating charge.	Weight of guncotton priming charge.	Composition of detonating charge.	
			Mercury fulminate.	Potassium chlorate.
	Grams.	*Grams.*	*Per cent.*	*Per cent.*
5	1.4766	0.0242	89.74	10.26
6	1.3954	.0235		
7	1.3259	.0217		
Average	1.3993	.0232		
Maximum variation from average weight of charge		[a].0783		

[a] 5.5 per cent of average.

Summary of results of tests of No. 7 detonators and electric detonators.

Sample.	Average weight of total charge.	Maximum variation from average weight of charge.	Average weight of sand finer than 30-mesh after sand test.	Maximum variation from average.
	Grams.	*Per cent.*	*Grams.*	*Per cent.*
M54 (detonators)	1.4554	2.8	46.96	2.0
M1595 (electric detonators)	1.4352	4.2	46.33	4.8
M1523 (electric detonators)	1.4225	5.5	48.18	2.4
Average	1.4377	4.2	47.16	3.1

NO 8 ELECTRIC DETONATORS.

Only one lot of No. 8 electric detonators, containing approximately 90 per cent of mercury fulminate and 10 per cent of potassium chlorate, was available for test. The results of tests of this lot follow.

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Results of sand tests of No. 8 electric detonators, sample M1562.

Test No.	Weight of sand finer than 30-mesh caught on—				Weight of sand through 100-mesh.	Total weight of sand finer than 30-mesh.
	40-mesh.	60-mesh.	80-mesh.	100-mesh.		
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
1	4.88	8.00	4.66	3.88	33.01	54.43
2	4.92	7.70	4.83	2.75	32.80	53.00
3	5.21	7.91	4.88	3.46	33.68	55.14
4	5.37	7.85	5.11	3.14	32.79	54.26
5	4.36	8.01	4.65	2.99	34.19	54.20
6	5.95	8.34	4.57	3.18	33.81	55.85
7	6.12	7.20	4.85	3.19	33.46	54.82
Average	5.26	7.86	4.79	3.23	33.39	54.53
Maximum variation from average						[a] 1.53

[a] 2.8 per cent of average.

Weight and composition of charge of No. 8 electric detonators, sample M1562.

Test No.	Weight of charge.	Composition of charge.	
		Mercury fulminate.	Potassium chlorate.
	Grams.	*Per cent.*	*Per cent.*
8	1.8053		
9	1.8235		
10	1.8016	89.42	10.58
11	1.8020		
12	1.8800		
Average	1.8345	89.42	10.58
Maximum variation from average	[a] .4550		

[a] 2.5 per cent of average.

As shown by the tables, the one lot of No. 8 detonators tested contained an average charge of 1.8345 grams and in the sand tests an average of 54.53 grams of standard sand was pulverized finer than 30 mesh. The 2.8 per cent variation in the weight of sand pulverized in sand tests agrees well with the 2.5 per cent variation in the weight of charge.

NO. 10 DETONATORS.

The one lot of No. 10 detonators tested containing the 90:10 composition gave the following results:

Results of sand tests of No. 10 detonators, sample M1665.

Test No.	Weight of sand finer than 30 mesh caught on—				Weight of sand through 100 mesh.	Total weight of sand finer than 30 mesh.
	40 mesh.	60 mesh.	80 mesh.	100 mesh.		
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
1	6.42	8.99	5.88	4.39	43.16	68.84
2	5.25	8.35	5.62	4.04	44.35	67.61
3	5.58	8.92	5.71	5.55	42.00	67.82
4	5.31	8.28	6.24	3.86	45.16	68.85
5	5.56	8.92	6.16	3.57	45.97	70.18
6	5.39	8.87	5.95	4.00	44.94	69.15
Average	5.58	8.72	5.94	4.24	44.26	68.74
Maximum variation from average						[a] 1.44

[a] 2.1 per cent of the average.

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Weight and composition of charge of No. 10 detonators, sample 1665.

Test No.	Weight of charge.	Composition of charge.	
		Mercury fulminate.	Potassium chlorate.
	Grams.	*Per cent.*	*Per cent.*
7	2.8240	87.31	12.69
8	2.9058		
9	2.8555		
10	2.8912		
Average	2.8691	87.31	12.69
Maximum variation from average	a.0451	.....	.....

a 1.6 per cent of the average.

In the sand tests of this sample of No. 10 detonators, with an average weight of 2.8691 grams of charge, an average of 68.74 grams of standard sand was pulverized finer than 30 mesh. The maximum variation from the average quantity of sand pulverized, 2.1 per cent, is only slightly greater than the variation from the average weight of charge, 1.6 per cent.

SUMMARY.

The results of the tests of commercial detonators and electric detonators containing approximately 90 per cent of mercury fulminate and 10 per cent of potassium chlorate are summarized in the following table:

Average results of sand tests of commercial detonators and electric detonators.

Grade No.	Number of lots tested.	Total number of detonators tested.		Average weight of sand finer than 30-mesh.	Average weight of charge.	Average maximum variation in—	
		Sand test.	Weight of charge.			Weight of sand finer than 30-mesh.	Weight of charge.
				Grams.	*Grams.*	*Per cent.*	*Per cent.*
3	1	10	10	22.03	0.4953	7.3	8.5
4	1	5	6	27.44	.6358	3.8	6.5
5	6	35	36	30.90	.7220	4.6	5.5
6	6	28	31	36.61	.9842	3.4	4.2
7	3	19	19	47.16	1.4377	3.1	4.2
8	1	7	5	54.53	1.8345	2.8	2.5
10	1	6	4	68.74	2.8691	2.1	1.6

The results justify the conclusions (1) that the total weight of sand granulated to a finer degree than 30-mesh bears a definite relation to the weight of charge; (2) that the variation in the quantity of sand pulverized finer than 30-mesh agrees well with the variations in the weight of charge.

The definite relation between the weight of charge and the total weight of sand pulverized is plainly shown by plotting the average weights of charge in the various grades of detonators as abscissas and the total weights of sand pulverized to a finer granulation than

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30 mesh as ordinates. The seven points thus obtained from the results of the tests outlined lie approximately on a regular curve as shown in figure 2.

TESTS OF COMMERCIAL DETONATORS CONTAINING APPROXIMATELY 80 PER CENT OF MERCURY FULMINATE AND 20 PER CENT OF POTASSIUM CHLORATE.

In order to ascertain the effect of an increase in the percentage of potassium chlorate and a corresponding decrease in the mercury fulminate content of the charge, tests were made of samples of a few lots of detonators that contained the 80:20 composition now employed by some manufacturers of detonators.

Two lots of No. 6 detonators, two lots of No. 6 electric detonators, and one lot of No. 8 detonators were tested. The results of the tests are shown in the following table:

Results of sand tests of detonators and electric detonators containing approximately 80 per cent of mercury fulminate and 20 per cent of potassium chlorate.

Grade and kind of detonator.	Designation of sample.	Weight of sand pulverized finer than 30-mesh in test No.—						Average weight of charge.	Composition of charge.	
		1	2	3	4	5	Average.		Mercury fulminate.	Potassium chlorate.
		Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	**Grams.**	*Grams.*	*P. ct.*	*P. ct.*
No. 6 detonator...	X.....	36.49	34 44	35.38	34.75	.....	35.27	0.8867	79.52	20.48
No. 6 detonator...	M1325...	37.76	38.91	36.60	38.62	36.47	37.67	.9267	84.94	15.06
No. 6 electric detonator.	M1673...	37.14	37.54	37.24	38.14	39.03	37.82	.9541	79.29	20.71
No. 6 electric detonator.	M1325X.	36.21	40.72	.....	.....	.....	38.47	.9210	84.94	15.06
No. 8 detonator...	M1661...	59.73	59.70	59.97	60.70	.....	60.03	1.9751	80.01	19.99

The average weight of charge of the No. 6 detonators and electric detonators was 0.9221 gram, and the average weight of sand pulverized finer than 30 mesh was 37.31 grams. The No. 8 detonators contained an average weight of charge of 1.9751 grams. In the sand test 60.03 grams of standard sand was pulverized finer than 30 mesh. If these results are plotted on the curve (fig. 2) obtained from the average results of sand tests of detonators containing the 90:10 composition, the resulting points, with one exception, lie above the curve shown in figure 2.

In figure 3, part of the curve shown in figure 2 is reproduced, and the average results of the tests of the detonators and electric detonators having the 80:20 composition are indicated.

The tests having indicated that the 80:20 mixture of fulminate and chlorate produces greater effects than an equal weight of the 90:10 mixture, it was considered advisable to make a more complete investigation of the relative effects produced by mixtures containing different proportions of the two ingredients, the results being compared with the effect of mercury fulminate alone.

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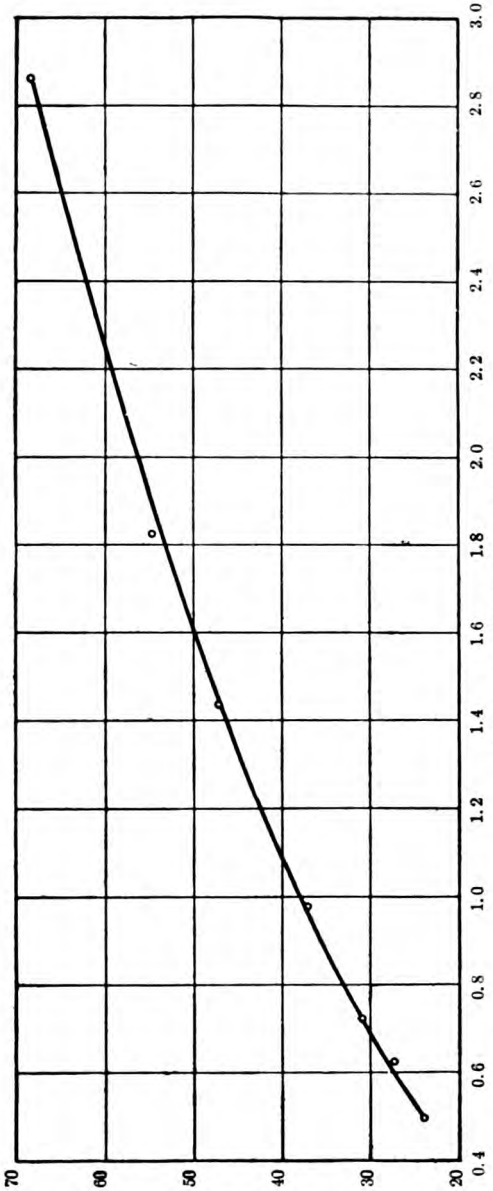

FIGURE 2.—Curve showing results of sand tests of various grades of detonators and electric detonators containing approximately 90 per cent of mercury fulminate and 10 per cent of potassium chlorate.

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RELATIVE STRENGTHS OF MERCURY FULMINATE AND ITS MIXTURES WITH POTASSIUM CHLORATE.

Many conflicting statements regarding the effect of adding potassium chlorate to mercury fulminate on its efficiency as a detonator are found in the literature.

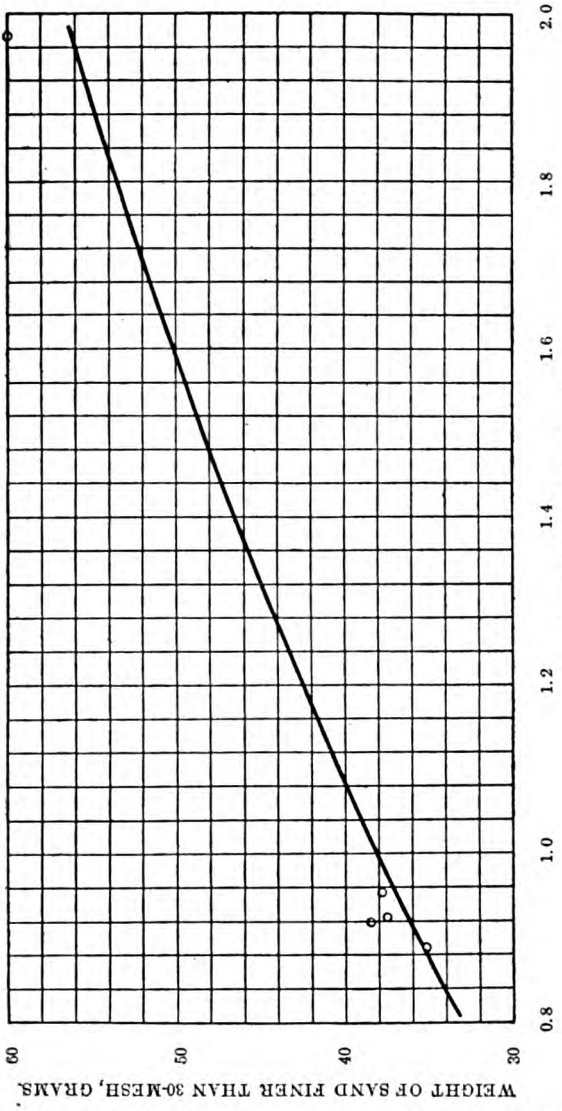

FIGURE 3.—Curve showing results of sand tests of various grades of detonators and electric detonators containing approximately 80 per cent of mercury fulminate and 20 per cent of potassium chlorate.

Hagen [a] states that the addition of potassium chlorate increases the calorific effect and the gas pressure, and thereby the efficiency of the detonator.

[a] Hagen, O., Ueber Zundsatzfabrication: Ztschr. gesamte Schiess- und Sprengstoffwesen, vol. 6, 1912, pp. 201, 224, 243.

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Gody [a] states that the pressure of a mixture of fulminate and chlorate is greater than that of fulminate alone, but that the initial shock is lessened by such addition.

According to Chalon [b] the addition of potassium chlorate to mercury fulminate lowers its brisance, or, in other words, moderates the violence of the shock resulting on explosion, although it increases the amount of heat evolved.

Weaver [c] states that the addition of oxidizing substances like potassium chlorate serves to increase the heat, both because the chlorate is endothermic and because the oxygen it supplies serves to burn the CO of the products of combustion of mercury fulminate to CO_2, and thus still further increases the heat.

Daniel [d] claims that 5 to 20 per cent of potassium chlorate added to mercury fulminate renders its action as a detonator more efficient.

Wöhler [e] states that the addition of chlorate gives a greater total energy but a lower velocity of detonation, and similar views are expressed by Berthelot,[f] these authorities being of the opinion that the velocity of detonation exerts the greatest influence on the efficiency of a detonating substance.

Thus, although many authorities concede that the addition of potassium chlorate to mercury fulminate probably results in a lowering of the detonating efficiency, others hold a different opinion.

THEORETICAL CONSTANTS OF MERCURY FULMINATE AND ITS MIXTURES.

A consideration of the theoretical constants calculated for mercury fulminate and its various mixtures with potassium chlorate leads to no definite conclusions in the matter. The volume of the gases of explosion, the amount of heat liberated, and the temperature of explosion have been calculated for (1) mercury fulminate, (2) a mixture of 90 per cent of mercury fulminate, and 10 per cent of potassium chlorate, (3) a mixture of 80 per cent of mercury fulminate and 20 per cent of potassium chlorate, and (4) a mixture of 77.66 per cent of mercury fulminate and 22.34 per cent of potassium chlorate.

The explosive reactions of these different detonating compositions are assumed to be as follows, the numbers in parentheses corresponding to those above.

---

[a] Gody, L., Traité théorique et pratique des matières explosives, 1907, p. 283.
[b] Chalon, P. F., Les explosifs modernes, 1911, p. 100.
[c] Weaver, E. M., Notes on military explosives, 1910, p. 171.
[d] Daniel, J., Dictionnaire des matières explosives, 1902, p. 193.
[e] Wöhler, L., Ueber Initialzündungen: Ztschr. angew. Chem., Jahrg. 24, 1911, pp. 2089-2099.
[f] Berthelot, M., Explosives and their power, 1892, p. 298 (translation by Hake and Macnab).

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(1) $HgC_2N_2O_2 = Hg + 2CO + N_2$

(2) $3.875HgC_2N_2O_2 + KClO_3 = KCl + 3.875Hg + 2.99CO_2 + 4.76CO + 3.875N_2$

(3) $1.722HgC_2N_2O_2 + KClO_3 = KCl + 1.722Hg + 3CO_2 + 0.444CO + 1.722N_2$

(4) $1.5HgC_2N_2O_2 + KClO_3 = KCl + 1.5Hg + 3CO_2 + 1.5N_2$

By calculation from these equations the following values were obtained :

Calculated constants.

Composition No.	Volume of gases of explosion (V).	Heat evolved (Q).	Explosion temperature.
	C. c. per gram.	*Calories per gram.*	° *C.*
1	314.8	362.0	4139
2	283.3	500.0	3888
3	251.8	639.0	3780
4	244.6	671.3	3760

The following values were used in calculating the constants tabulated above :

Values used in calculating constants.

Element or compound.	Specific heat (constant volume).	Authority.
CO_2	$6.26+0.0037t$	Mallard and Le Chatelier.[a]
CO	$4.80+0.0006t$	Mallard and Le Chatelier.[a]
N_2	$4.80+0.0006t$	Mallard and Le Chatelier.[a]
Hg (gaseous)	3.00	Lewis and Randall.[b]
Hg (liquid)	$(200\times0.033)=6.60$	Gody.[c]
KCl	$12.74+0.0002t$	Kopp..[d]

Element or compound.	Heat of formation.	Authority.
$HgC_2N_2O_2$	− 62,900	Berthelot.[e]
$KClO_3$	+ 95,800	Thomsen.[f]
KCl	+105,600	Thomsen.[f]
CO_2	+ 94,300	Berthelot.[g]
CO	+ 26,100	Berthelot.[g]

Volume of 1 gas molecule at 0° C. and 760 mm., 22.4 liters.

Correction for each gas molecule to constant volume, 545 calories.

Molecular heat of volatilization of mercury at its boiling point (358° C.), 13,000 calories.[h]

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[a] Mallard and Le Chatelier, Sur les chaleurs spécifiques des gaz aux températures élévés: Compt. rend. t. 93, 1881, p. 1014.

[b] Lewis, G. N. and Randall, M., Summary of the specific heats of gases: Jour. Am. Chem. Soc., vol. 34, 1912, p. 1128

[c] Gody, L., Traité théorique et pratique des matierès explosives, 1907, p. 215.

[d] Kopp, Hermann, Ueber die specifische Wärme der starren Körper: Annalen der Chem. u. Pharm., Suppl. 3, 1864–65, p. 289.

[e] Landolt and Börnstein, Physikalisch-chemische Tabellen, 1912, p. 870 (M. Berthelot).

[f] Landolt and Börnstein, Physikalisch-chemische Tabellen, 1912, p. 860 (J. Thomsen).

[g] Landolt and Börnstein, Physikalisch-chemische Tabellen, 1912, p. 855 (M. Berthelot).

[h] Landolt and Börnstein, Physikalisch-chemische Tabellen, 1912, p. 223 (Person and Kurbatoff).

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The calculated values shown in the table on page 36 show that the addition of potassium chlorate to mercury fulminate in quantities up to the amount required for complete combustion of the carbon to CO_2 (composition 4) causes a decrease in the volume of gas evolved on explosion, accompanied by a marked increase in the amount of heat liberated per gram of explosive. In spite of this relatively great increase in the heat evolved, the resulting temperature of explosion is slightly lowered by the addition of the chlorate, because of the increased specific heat of the products of explosion.

RELATION OF RATE OF DETONATION OF INITIAL DETONATORS.

It is generally assumed that a high rate of detonation is an essential property of an initial detonator, and, as noted above, various authorities claim that the addition of potassium chlorate to mercury fulminate gives a weaker detonator because the rate of detonation of the mixture is lower than that of the pure fulminate. The writers have no knowledge of the existence of any experimental comparisons of the rates of detonation of mercury fulminate alone and in admixture with potassium chlorate, and even were the results of such determinations available it would be impossible to draw definite conclusions as to the assumption mentioned. For example, many explosives having much higher rates of detonation than mercury fulminate do not possess to any degree the property of initiating the explosion of other high explosives. Blasting gelatin, containing approximately 93 per cent of nitroglycerin and 7 per cent of nitrocellulose, was found by Bichel [a] to have a rate of detonation of 7,700 meters per second, whereas he obtained only 3,920 meters per second for mercury fulminate. Nitroglycerin has been found to detonate at a velocity of over 7,000 meters per second, [b] its temperature of detonation has been calculated as 3,155° C., and the heat liberated by its explosion is 1,468 calories per gram. [c]

In spite of the fact that these explosives are far superior to mercury fulminate in rate of detonation and evolution of total energy, they have not the properties that fit them for use as initial detonators, whatever such requirements may be.

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[a] Bichel, C. E., Ueber Zündungen von Sprengstoffen: Glückauf, Jahrg. 40, 1904, p. 1043, and Jahrg, 41, 1905, p. 1195.

[b] Comey, A. M., and Holmes, F. B., Method for the determination of the effective strength of high explosives: Proc. 8th Int. Cong. Appl. Chem., vol. 25, 1912, p. 220.

[c] Hall, Clarence, Snelling, W. D., and Howell, S. P., Investigations of explosives used in coal mines: Bull. 15, Bureau of Mines, 1912, p. 31.

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PHYSICAL CHARACTERISTICS OF MERCURY FULMINATE AND LEAD NITRIDE.

A comparison of the physical characteristics of detonating substances of different nature also fails to throw light on the question. If, for example, mercury fulminate be compared with lead hydronitride (commonly known as lead nitride or lead azide, PbN_6), the natural conclusion is that the former should be superior as a detonator. Stettbacher [a] gives the following comparative values:

Comparison of physical characteristics of mercury fulminate and lead nitride.

	Mercury fulminate.	Lead nitride.
Heat evolved, calories per gram	397	364
Explosion temperature, °C	3,594	3,483
Explosion pressure, kilograms per square centimeter	Infinite.	96,080
Work density, kilogram meters per cubic centimeter	152.15	98.96
Density of charge, grams per cubic centimeter	3.298	3.01

The above comparison is in every respect favorable to mercury fulminate. However, practical tests of these two detonating substances have shown that mercury fulminate is much inferior to lead nitride as regards capacity for initiating the detonation of certain of the nitrosubstitution compounds. The results tabulated below are quoted by Stettbacher [b] as having been obtained by Martin [c] in a determination of the minimum charges of initial detonators required to completely detonate 0.5-gram charges of the nitrosubstitution compounds, the combined charge being compressed at a pressure of 1,100 kilograms per square centimeter in the so-called reinforced detonators.

Comparison of detonating efficiencies of mercury fulminate and lead nitride.

Initial detonator.	Minimum charge of initial detonator, giving complete detonation of—			
	Tetranitromethyl aniline.	Picric acid.	Trinitrotoluene.	Trinitroanisol.
	Grams.	*Grams.*	*Grams.*	*Grams.*
Mercury fulminate	0.29	0.30	0.36	0.37
Lead nitride	.025	.025	.09	.28

These results show the marked superiority of lead nitride over mercury fulminate as an initial detonator, and demonstrate the impossibility of drawing definite conclusions from a comparison of calculated values such as those discussed above.

[a] Stettbacher, A., Altes und neues über Initialzündungen: Ztschr. gesamte Schiess- und Sprengstoffwesen, vol. 9, 1914, p. 341.

[b] Stettbacher, A., Loc. cit.

[c] Martin, —, Über Azide und Fulminate, pp. 41–44.

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COMPARISON TESTS OF RATE OF DETONATION OF PRIMING COMPOSITION.

PROCEDURE IN TESTS.

In view of the difficulties connected with exact determinations of the rate of detonation of priming compositions, simple comparison tests were made with a view to showing in some measure the relative rates of detonation of different compositions. In these tests a small definite weight of a detonator composition was placed in a small glass test tube, without stopper, and heated rapidly over a small flame until it exploded, when observation was made as to whether the tube had been broken by the explosion. The test tubes were about 7.5 cm. long and 1 cm. in diameter, of thin glass, and approximately uniform as to size and weight. The tests were conducted in a special protecting cabinet, each tube being fastened in a loose clamp on an iron stand and drawn directly over the flame of a burner by means of a string attached to the clamp. In this manner danger from flying glass was avoided.

By varying the weights of the different compositions tested, it was found that the different compositions could be graded as to their shattering effects.

RESULTS OF TESTS.

The results of the tests are shown below.

Results of tests of shattering effect of mercury fulminate and of mixtures of fulminate and chlorate.

Charge.		Weight of charge (grams).							
		0.04		0.05		0.06		0.07	
Constituent.	Per cent.	Number of times tube broken.	Number of times tube not broken.	Number of times tube broken.	Number of times tube not broken.	Number of times tube broken.	Number of times tube not broken.	Number of times tube broken.	Number of times tube not broken.
Mercury fulminate	100	.....	.....	2	8	5	5	10	0
Mercury fulminate	90	0	10	7	3	9	1	.....	.....
Potassium chlorate	10								
Mercury fulminate	80	2	8	9	1	.....	.....	.....	.....
Potassium chlorate	20								

COMMENTS ON RESULTS.

The results show that 0.05 gram of pure mercury fulminate caused the tubes to be broken in only 20 per cent of the trials, and 0.06 gram in 50 per cent of the trials; 0.04 gram of the 90:10 composition failed to break the tubes in all trials, but 0.05 gram broke the tubes in 70 per cent of the trials, and 0.06 gram in 90 per cent of the trials;

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the 80:20 composition showed the greatest effects, 0.04 gram shattering the tubes in 20 per cent, and 0.05 gram in 90 per cent of the trials.

The particular property of detonating compositions on which shattering effect depends appears to be its initial rate of detonation. The effect is purely local, just as the action of a detonator on a secondary explosive is entirely local, the detonator initiating the explosion of that part of the explosive charge immediately surrounding it, and the rate of detonation of the remainder of the explosive charge being dependent on characteristics of the explosive itself as well as on the effectiveness or violence of the initial force of the detonator.

The results of the tests represented in the table are entirely confirmatory of the results of the sand tests in which the chlorate mixtures, especially the 80:20 composition were shown to be superior to pure mercury fulminate, both in effectiveness in crushing sand and in effectiveness in causing complete detonation of various nitrosubstitution compounds.

A few tests made with lead nitride, to determine its shattering effects for comparison with those of the fulminate compositions, showed that an amount of lead nitride as small as 0.01 gram would invariably shatter the tube completely, whereas even 0.001 gram in every trial drove the bottom out of the tube. These results correspond with those obtained by other investigators (see p. 38) and confirmed by the writers, which showed that priming charges of even 0.025 gram of lead nitride were capable of bringing about complete detonation of certain nitrocompounds in reinforced detonators, as compared with the much larger amounts of fulminate compositions required to produce the same result.

The writers believe that the efficiency of detonating compositions in bringing about the complete detonation of secondary explosives depends on some property or combination of properties that has not been successfully determined or measured, and that the initial rate of detonation of the priming composition is one of the factors of greatest importance. It is furthermore likely that this initial rate of detonation is much greater than the rate of detonation determined by the usual methods employed in testing blasting explosives, in which a column of explosive of considerable length is employed.

SAND TESTS OF UNCOMPRESSED CHARGES OF MERCURY FULMINATE AND ITS MIXTURES.

A lot of No. 7 detonators containing an average weight of charge of 1.4600 grams of the 90:10 composition was subjected to the sand test and pulverized 46.96 grams of sand finer than 30 mesh (sample M54, pp. 27–28). The composition was removed from a number of detonators selected from this lot, and charges equal to the average

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weight of charge, 1.4600 grams, were placed in empty copper shells such as are used for blasting caps, and were packed slightly by simply tapping the caps on the table top. Thus, these laboratory-made detonators differed from sample M54 merely in that they contained the composition in an uncompressed condition, the charge in the regular detonators being compressed under a pressure of approximately 100 to 200 atmospheres per square inch.

The results of sand tests of the laboratory-made detonators agreed remarkably well with those of the regular detonators (sample M54), as may be seen by comparing the following table with the results obtained with those detonators (pp. 27–28).

Results of sand tests of detonators with uncompressed charge of 1.46 grams of 90:10 composition.

Test No.	Weight of sand pulverized finer than 30-mesh caught on—				Weight of sand through 100-mesh.	Total weight of sand finer than 30-mesh.
	40-mesh.	60-mesh.	80-mesh.	100-mesh.		
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
1	5.27	7.35	5.22	2.94	26.83	47.61
2	5.28	8.10	4.05	2.90	29.33	49.66
3	4.66	6.88	4.25	3.07	26.36	45.22
4	4.43	7.48	4.63	2.98	29.04	48.56
5	4.76	7.65	4.52	3.16	27.63	47.72
Average	4.88	7.49	4.53	3.01	27.84	47.75
Average of sand tests of sample M54	4.74	7.09	4.36	3 06	27.71	46.96

The above comparison shows such a remarkable agreement of results, even as to the weights of the separate fractions of the different granulations, that it appears evident that the strength of a mercury fulminate detonator, as indicated by the effect produced in crushing sand, is not influenced by variations in the density of the charge up to the density found in commercial detonators.

It is well known that mercury fulminate compositions may be "dead-pressed," that is, compressed to such density that they will not detonate but merely burn on contact with flame.

The tests with uncompressed charges showed that it was possible to make sand tests of uncompressed charges the results of which would be comparable with those obtained in tests of commercial detonators, thus providing a means of testing accurately weighed charges of different compositions.

In the tests represented in the table following, the charges were accurately weighed, transferred to copper shells approximately 40 mm. long, 7 mm. in outside diameter, and 6.60 mm. in inside diameter, and slightly packed by tapping the shell. The shell was then crimped in the usual manner on a short length of black-powder fuse, and the sand test was made as before described.

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DETAILS OF TESTS OF THREE COMPOSITIONS.

Three compositions were tested in this manner, as follows: (1) Mercury fulminate alone, without admixture of potassium chlorate; (2) a mixture of 90 per cent of mercury fulminate and 10 per cent of potassium chlorate; and (3) a mixture of 80 per cent of mercury fulminate and 20 per cent of potassium chlorate. The results were as follows:

Results of sand tests of detonators containing three different weighed charges.

MERCURY FULMINATE, WITHOUT POTASSIUM CHLORATE.

Weight of charge.	Weight of sand pulverized finer than 30-mesh caught on—				Weight of sand through 100-mesh.	Total weight of sand finer than 30-mesh.
	40-mesh.	60-mesh.	80-mesh.	100-mesh.		
Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
2.0000	4.90	8.02	4.85	3.22	35.95	56.94
1.5000	4.42	7.10	4.22	2.80	29.17	47.71
1.0000	4.53	6.30	3.85	2.77	20.88	38.33
.7500	3.75	5.33	2.83	1.82	15.92	29.65
.5000	3.74	4.44	2.39	1.40	10.48	22.45
.4000	3.06	3.57	1.95	1.07	8.26	17.91
.3500	2.55	2.80	1.54	.82	6.45	14.16
.3250	1.83	2.53	1.27	.70	5.87	12.20
.3000	1.92	2.13	1.05	.57	4.34	10.01
.2500	1.60	2.05	1.10	.65	3.44	8.84
.2250	1.45	1.57	.77	.52	2.62	6.93
.2000	1.60	1.20	.62	.34	1.72	5.48
MERCURY FULMINATE (90 PER CENT) AND POTASSIUM CHLORATE (10 PER CENT).						
2.0000	5.09	8.02	5.21	3.32	31.93	58.57
1.5000	4.89	7.84	4.78	2.82	30.78	51.11
1.0000	5.00	6.69	3.82	2.61	22.01	40.13
.7500	4.30	5.82	3.24	2.01	16.93	32.30
.5000	3.60	4.49	2.46	1.36	11.16	23.07
.4000	3.04	3.92	1.91	1.11	7.92	17.90
.3500	2.50	3.06	1.54	.89	7.14	15.13
.3250	2.05	2.71	1.37	.72	6.05	12.90
.3000	2.40	2.69	1.35	.74	5.53	12.71
.2500	1.95	2.29	1.29	.72	3.32	9.57
.2250	1.83	2.00	1.10	.55	3.23	8.71
.2000	1.50	1.85	1.07	.69	3.15	8.33
MERCURY FULMINATE (80 PER CENT) AND POTASSIUM CHLORATE (20 PER CENT).						
2.0000	5.06	8.47	5.03	3.77	37.35	59.68
1.5000	4.92	8.07	4.85	3.40	31.30	52.54
1.0000	4.54	7.17	4.44	2.47	22.80	41.42
.7500	4.44	6.38	3.73	2.13	17.60	34.28
.5000	3.42	4.71	2.59	1.43	11.07	23.22
.4000	2.95	3.75	1.95	1.09	8.39	18.13
.3500	2.47	3.17	1.65	.90	7.75	15.94
.3250	1.97	2.87	1.44	.85	6.00	13.13
.3000	2.35	2.75	1.34	.72	5.45	12.61
.2500	2.50	2.80	1.52	.72	4.40	11.94
.2250	1.80	2.47	1.25	.67	4.10	10.29
.2000	1.90	2.15	1.25	.57	3.57	9.44

COMMENTS ON TABULATED DATA.

The detailed results shown in the table confirm the evidence presented by the tests of the commercial detonators—that the 80:20 composition possesses greater strength, as indicated by the

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sand test, than the 90:10 composition, and that both compositions are stronger than mercury fulminate alone.

A comparison of the results contained in the last column of the table is facilitated by the following table, in which these results are placed side by side:

Comparison of results of sand tests of weighed charges of mercury fulminate, 90:10 composition, and 80:20 composition.

Weight of charge.	Total weight of sand pulverized finer than 30-mesh.		
	Mercury fulminate.	Mercury fulminate (90 per cent) and potassium chlorate (10 per cent).	Mercury fulminate (80 per cent) and potassium chlorate (20 per cent).
Grams.	*Grams.*	*Grams.*	*Grams.*
2.0000	56.94	58.57	59.68
1.5000	47.71	51.11	52.54
1.0000	38.33	40.13	41.42
0.7500	29.65	32.30	34.28
0.5000	22.45	23.07	23.22
0.4000	17.91	17.90	18.13
0.3500	14.16	15.13	15.94
0.3250	12.20	12.90	13.13
0.3000	10.01	12.71	12.61
0.2500	8.84	9.57	11.94
0.2250	6.93	8.71	10.29
0.2000	5.48	8.33	9.44

The results of the foregoing table are plotted in figure 4, where they are seen to follow closely regular curves.

RELATIVE EFFICIENCY OF MERCURY FULMINATE ALONE AND IN MIXTURES WITH POTASSIUM CHLORATE AS INITIAL DETONATOR FOR NITROSUBSTITUTION COMPOUNDS.

The results of sand tests discussed in the foregoing pages showed that, as regards efficiency in the pulverization of sand, mercury fulminate alone is inferior to both of the commonly used 90:10 and 80:20 mixtures of mercury fulminate and potassium chlorate, and that the 80:20 mixture is superior to the 90:10 mixture. It then appeared advisable to make actual comparisons of the relative efficiencies of these detonator compositions in bringing about the complete detonation of various nitrosubstitution compounds.

The sand test offered a most suitable means of carrying out such determinations as a comparison of the weights of sand pulverized would serve to indicate whether complete explosion of the nitrosubstitution compound was effected. Furthermore, if there is an incomplete explosion in making the sand test, the unexploded part of the charge, contained in the bottom part of the copper shell, is recovered in the sand on emptying the bomb. (See Pl. II, *A*.)

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METHOD USED IN PRELIMINARY TESTS.

The method adopted in the preliminary tests was as follows:

Four-tenths of a gram of the nitrosubstitution compound to be used was weighed on a small sheet of glazed paper, transferred to

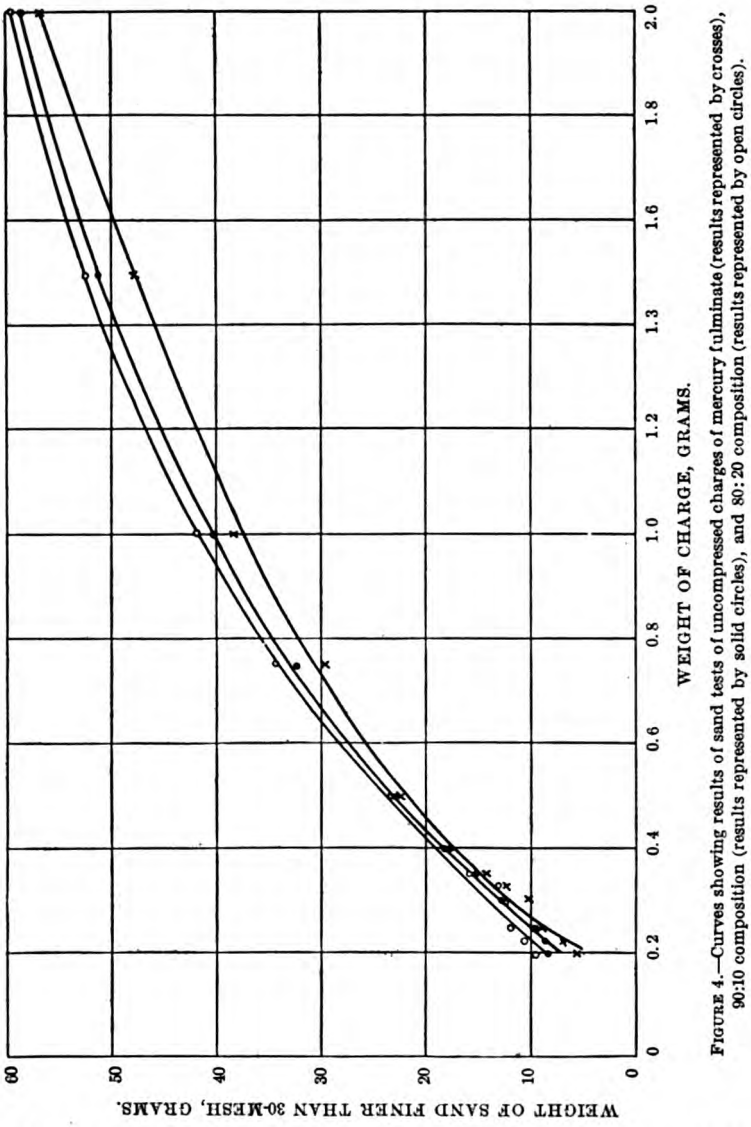

FIGURE 4.—Curves showing results of sand tests of uncompressed charges of mercury fulminate (results represented by crosses), 90:10 composition (results represented by solid circles), and 80:20 composition (results represented by open circles).

one of the copper detonator shells, 40 mm. long by 6.60 mm. in inside diameter, and slightly compressed by means of a glass rod fitting neatly into the shell.

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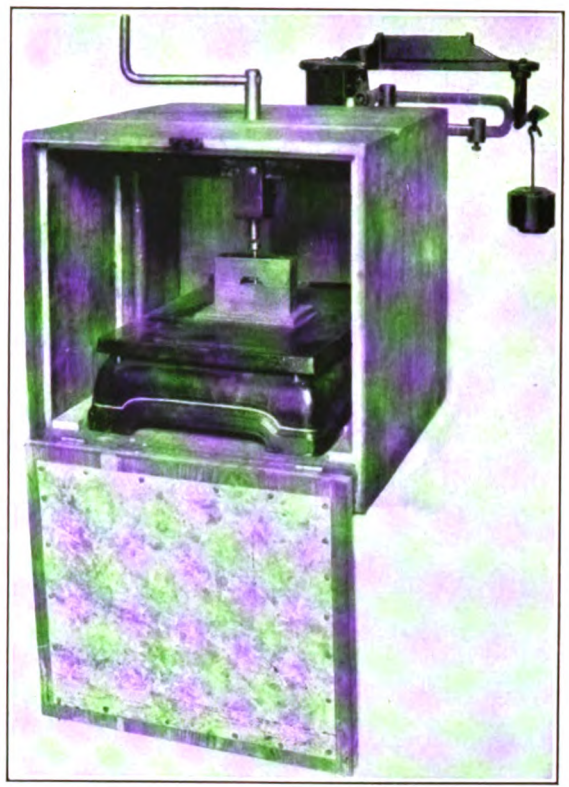
A. RESULTS OF INCOMPLETE EXPLOSION OF REINFORCED DETONATORS IN THE SAND TEST.



B. APPARATUS FOR COMPRESSING CHARGE IN DETONATOR.

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A weighed charge of the priming composition, either mercury fulminate or one of its mixtures with potassium chlorate, was then added on top of the nitrocompound, and packed slightly by tapping the shell lightly against the table top. A short length of black-powder fuse was then inserted, the shell crimped to the fuse, and the combined charge fired in the bomb in the manner previously described.

By suitable reductions in the weight of the priming charge, the weight of charge of nitrocompound being kept constant (0.4 gram), it was possible to determine approximately the minimum charge of each priming composition that would completely detonate the constant charge of nitrocompound, the weight of sand pulverized serving as an indication of the completeness of the detonation.

TESTS OF TETRANITROMETHYLANILINE.

The results of complete tests of tetranitromethylaniline, or "tetryl," tabulated below will illustrate the method of procedure followed with each of the nitrosubstitution compounds tested.

Results of detonation tests of tetranitromethylaniline (tetryl).

Priming charge.		Weight of tetryl.	Weight of sand finer than 30-mesh caught on—				Weight of sand through 100-mesh.	Total weight of sand finer than 30-mesh.
Composition.	Weight.		40-mesh.	60-mesh.	80-mesh.	100-mesh.		
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
Mercury fulminate	0.5000	0.4000	4.74	7.15	4.45	3.09	27.35	46.78
	.4000	.4000	4.93	6.55	4.06	2.79	22.50	40.83
	.3500	.4000	4.60	6.29	3.89	2.50	19.13	36.41
	.3250	.4000	3.80	3.03	2.07	1.13	6.93	16.96
Mercury fulminate (90 per cent) and potassium chlorate (10 per cent)	.3250	.4000	4.73	6.43	3.71	2.37	21.05	38.29
	.3000	.4000	4.81	6.75	3.57	2.70	20.16	37.99
	.2750	.4000	3.11	3.75	1.85	.98	5.92	15.61
Mercury fulminate (80 per cent) and potassium chlorate (20 per cent)	.3000	.4000	4.67	6.28	3.83	2.32	18.78	35.88
	.2750	.4000	4.82	6.51	3.95	2.46	18.40	36.14
	.2500	.4000	3.02	3.58	1.73	1.03	5.64	15.00

It is apparent that in the tests represented in the foregoing table complete detonation of the 0.4 gram of "tetryl" was obtained by means of a priming of at least 0.3500 gram of pure mercury fulminate, 0.3000 gram of the 90:10 mixture, and 0.2750 gram of the 80:20 mixture. The decided decrease in the pulverizing effect of the detonators when the weight of the priming charges was reduced 0.0250 gram less than the weights given shows conclusively that with the weaker priming charges complete detonation of the "tetryl" was not obtained. Furthermore, in each test in which the quantity of sand pulverized indicated incomplete detonation, the bottom part of the copper shell containing unexploded "tetryl" was recovered from the bomb when the sand was sifted. (See Pl. II, *A*.)

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TESTS OF OTHER NITROSUBSTITUTION COMPOUNDS.

A large number of tests were also made to determine the minimum weights of charge of the three priming compositions necessary to effect complete detonation of tetranitroaniline and picric acid. It is not necessary to present the detailed results of the tests, but a summary of the results is given in the following table. The weight of nitrosubstitution compound in all tests was 0.4000 gram. The minimum weight of each of the three priming compositions that produced complete detonation of each nitrocompound, and the results of the sand test in terms of the total weight of sand pulverized to a finer granulation than 30-mesh, are shown in the table.

Results of detonation tests of three nitrocompounds.

Nitrocompound.		Priming charge.			Total weight of sand finer than 30-mesh.
		Composition.		Minimum weight for complete detonation.	
Designation.	Weight.	Mercury fulminate.	Potassium chlorate.		
	Grams.	*Per cent.*	*Per cent.*	*Grams.*	*Grams.*
Tetranitromethylaniline	0.4000	100		0.3500	36.41
Do	.4000	90	10	.3000	37.99
Do	.4000	80	20	.2750	36.14
Tetranitroaniline	.4000	100		.4500	40.50
Do	.4000	90	10	.3125	35.39
Do	.4000	80	20	.3125	35.08
Picric acid	.4000	100		.4000	36.65
Do	.4000	90	10	.3750	35.04
Do	.4000	80	20	.3750	37.60

The results of the tests show the superiority of the chlorate mixtures over pure mercury fulminate as a detonator for each of the three nitrocompounds, thereby confirming the results of the sand tests tabulated on pages 42 to 43.

Under the conditions of the tests described above, trinitrotoluene could not be detonated by priming charges of as much as 1 gram of mercury fulminate or of its mixtures with chlorate, the weight of sand pulverized by the combined charge being only approximately that which should result from the detonation of the priming charge alone. A part of the trinitrotoluene contained in the bottom of the partly demolished copper shell (see Pl. II, *A*) was in each test recovered from the bomb by emptying the sand into the sieve. The failure of the priming charge to effect the detonation of the trinitrotoluene is apparent from the results shown below, obtained with combination charges of 0.4 gram of trinitrotoluene and 1.0 gram of 80:20 composition, the combined charge being prepared as described above.

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Results of detonation tests of trinitroluene (unconfined).

Priming charge.		Weight of trinitrotoluene.	Weight of sand finer than 30-mesh caught on—				Weight of sand through 100-mesh.	Total weight of sand finer than 30-mesh.
Composition.	Weight.		40-mesh.	60-mesh.	80-mesh.	100-mesh.		
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
Mercury fulminate (80 per cent) and potassium chlorate (20 per cent).	1.0000	0.4000	4.72	7.55	4.27	3.09	26.29	45.92
	1.0000	.4000	4.40	7.67	5.02	4.90	23.90	45.89
	1.0000	.4000	4.15	7.23	4.75	3.20	25.75	45.08
								[a] 45.63

[a] Average.

The average result of the sand tests of the combined charges, expressed as the total weight of sand pulverized finer than 30-mesh, is shown in the last column as 45.63 grams. The table on page 43 shows that 1 gram of the 80:20 composition alone, tested under like conditions, gave a result of 41.42 grams, which is sufficiently near to the average of the tests last mentioned to show that detonation of the trinitrotoluene was not effected under the conditions of the tests.

PREPARATION AND TESTS OF "REINFORCED" DETONATORS.

Certain commercial detonators contain as the main detonating charge a nitrosubstitution compound, such as trinitrotoluene, tetranitroaniline, or tetranitromethylaniline. The detonation of this charge is effected by means of a small priming charge of mercury fulminate or a mixture of the latter with potassium chlorate. The combined charge is given greater confinement by means of a small copper shell fitting neatly within the detonator shell and pressed on the charge. A small perforation about 2.3 mm. in diameter in the upper end of the reinforcing cap permits the ignition of the priming charge by the flame from the fuse.

This increased confinement undoubtedly has the effect of confining the force of the detonation of the priming charge so that this force can be more completely utilized for causing the detonation of the main charge of nitrocompound. The priming charge more quickly attains its maximum velocity of detonation under the increased confinement, and its effectiveness is thereby increased. Hence a smaller priming charge can be made to produce the desired result than would be required without the use of the reinforcing cap.

Figure 5 is a sectional view of a commercial reinforced detonator showing the arrangement of the charge. As indicated in the figure, in compressing the reinforcing cap on the charge, the resistance of

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the latter against the walls of this inner cap slightly expands the walls of the outer shell of the detonator, causing a more firm retention of the inner cap.

It was considered advisable to prepare in the laboratory reinforced detonators containing known weights of nitrocompound and of priming charge compressed at definite pressures, in order that a series of sand tests might be made to investigate the effects of such variables as compression, weight, and composition of priming charge on the different nitrocompounds employed in such detonators.

For convenience, in subsequent allusions to the three nitrosubstitution compounds mentioned, the commonly employed abbreviations are used, as follows: Trinitrotoluene, T. N. T.; tetranitromethylaniline, tetryl; tetranitroaniline, T. N. A.

LABORATORY APPARATUS FOR PRESSING DETONATORS.

The apparatus employed for pressing the charges is illustrated in Plate II, *B*. It consists essentially of an iron block provided with a hole in which the detonator is placed, an iron plunger fitting neatly within the detonator shell, a guide block through which the plunger passes, and an iron screw for obtaining the desired pressure against the upper end of the plunger. The detonator block is doweled to the platform of a counter platform scale with a capacity of 200 pounds. A wooden box surrounds the entire apparatus with the exception of the arm and beam of the scales and the upper end of the screw. The iron frame through which the screw passes is fastened in position within the box. The front of the box is hinged, provided with a catch fastener, and lined with heavy sheet iron as a protection from fragments of metal that might be projected by the explosion of a detonator. The diameter of the end of the plunger being 5 mm., corresponding to an area of one-thirtieth of a square inch, any desired pressure up to 6,000 pounds (400 atmospheres) per square inch is obtained by using a beam weight equal to one-thirtieth of the pressure desired, and turning the screw until the pressure on the detonator charge is such that the beam is in equilibrium.

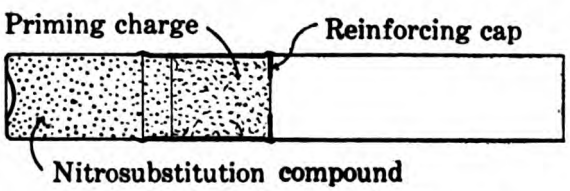

FIGURE 5.—Sectional view of reinforced detonator.

METHOD OF LOADING REINFORCED DETONATORS.

In loading the detonators the safest procedure is to place the weighed charge of nitrocompound in the detonator shell, and the weighed charge of priming composition in the small reinforcing cap,

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the latter being held in a small cavity in a brass block so that the composition will not be lost out of the hole in the end of the cap. The priming composition is then packed in the cap by slight pressure with a wooden rod, the cap is completely filled with a part of the weighed charge of nitrocompound packed in the same manner, and the small cap is removed from the brass block and carefully inserted in the detonator shell with its perforated end upward. The detonator is then placed in the press block, the plunger inserted on top of the reinforcing cap, and the desired pressure applied by means of the screw, care being taken to close the door of the box before applying the pressure, thereby avoiding accident from a possible explosion of the detonator. For the sake of uniformity the desired pressure on the charge was in each instance maintained for a definite period, one minute being selected as a suitable time for obtaining equilibrium of compression throughout the charge.

All of the "reinforced" detonators prepared in the laboratory for use in the tests described below were loaded by the method just described.

SAND TESTS OF T. N. T. REINFORCED DETONATORS.

The experiments were at first confined to sand tests of a single nitrocompound, trinitrotoluene (T. N. T.), and the effect of such variables as charging pressure, weight of priming charge, purity of nitrocompound, and size of crystals of nitrocompound were investigated, the same priming composition being used in all of the tests.

The relative efficiencies of different priming compositions for bringing about the complete detonation of various nitrocompounds was then studied by determining the minimum weight of each priming composition that would completely detonate a uniform charge of each of the different nitrocompounds.

Some results of incomplete detonation of reinforced detonators are shown in Plate II, *A*.

EFFECT OF VARIATIONS IN CHARGING PRESSURE AND WEIGHT OF PRIMING CHARGE.

PRIMING CHARGE CONTAINING 89.71 PER CENT OF MERCURY FULMINATE AND 10.29 PER CENT OF POTASSIUM CHLORATE.

The effect of variations in the charging pressure and in the weight of the priming charge was studied with a sample of T. N. T. designated sample 227, 0.4000 gram of the sample being used in each test. The priming composition was designated sample M54, and contained 89.71 per cent of mercury fulminate and 10.29 per cent of potassium chlorate. Tabulated results of the tests follow.

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Results of sand tests of sample 227 of T. N. T. with different charging pressures and weights of priming charge.

[Priming composition (sample M54), 89.71 per cent of mercury fulminate and 10.29 per cent of potassium chlorate.]

Weight of priming composition.	Total weight of sand pulverized finer than 30-mesh by detonator charged under pressure of—							
	400 atmospheres.	300 atmospheres.	250 atmospheres.	200 atmospheres.	100 atmospheres.	75 atmospheres.	50 atmospheres.	25 atmospheres.
Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
0.3200	34.10	36.22	35.70	35.20	36.22	35.72	35.70	.....
	34.10	.....	.....	.....	.....	.....	.....	.....
.31	.....	.....	.....	35.05	.....	.....	.....	.....
.30	.....	.....	.....	34.52	.....	.....	.....	.....
.29	.....	.....	.....	35.80	.....	.....	.....	.....
.28	.....	.....	.....	33.84	.....	.....	.....	.....
.27	.....	.....	.....	34.64	.....	.....	.....	.....
.26	31.40	34.25	.....	34.72	34.97	.....	34.82	34.67
	30.74	.....	.....	34.05	.....	.....	.....	.....
	29.50	.....	.....	32.64	.....	.....	.....	.....
	.....	.....	.....	33.15	.....	.....	.....	.....
.25	32.80	33.45	.....	33.82	34.87	.....	34.62	33.70
	.....	.....	.....	34.34	34.34	.....	.....	.....
.24	10.55	[a] 27.60	.....	.....	.....	.....	.....	.....
	.....	[a] 13.69	.....	31.80	32.44	.....	.....	.....
.23	.....	.....	.....	[a] 13.32	28.55	.....	.....	.....
.22	.....	.....	.....	.....	[a] 14.00	.....	28.90	.....
	.....	.....	.....	.....	.....	.....	33.60	.....
.21	.....	.....	.....	.....	.....	.....	32.15	.....
.20	.....	.....	.....	.....	.....	.....	27.75	.....
.19	.....	.....	.....	.....	.....	.....	26.25	.....
	.....	.....	.....	.....	.....	.....	31.95	.....
.18	.....	.....	.....	.....	[a] 10.75	[a] 21.57	[a] 12.07	[a] 11.05
	.....	.....	.....	.....	.....	.....	[a] 11.00	.....

[a] Incomplete detonation of T. N. T.

In every test represented in the foregoing table it will be noted that a priming charge as low as 0.2500 gram of 90:10 composition produced complete detonation of the T. N. T., as indicated by the sand test, when pressures varying from 400 to 25 atmospheres were employed in charging the detonators. As the weight of priming charge was reduced to less than 0.2500 gram, the probability of complete detonation was increased as the pressure was decreased. Thus, the minimum priming charge producing complete detonation was 0.25 gram for a compression of 400 atmospheres, 0.25 gram for a compression of 300 atmospheres, 0.24 gram for a compression of 200 atmospheres, 0.23 gram for a compression of 100 atmospheres, and 0.19 gram for a compression of 50 atmospheres.

The tests therefore showed that, although the particular sample of T. N. T. used could not be detonated by a priming charge of 1 gram of the fulminate composition without the additional confinement afforded by the reinforcing cap, the use of the reinforcing cap, even when a pressure as low as 50 atmospheres (750 pounds per square inch) was used in charging, enabled a priming charge of only 0.19 gram of the fulminate composition to cause complete detonation of the T. N. T. As the charging pressure was increased, the sensitiveness of the T. N. T. to detonation diminished, so that when pressure

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corresponding to a charging pressure of 400 atmospheres (6,000 pounds per square inch) was used, a priming charge of 0.25 gram was necessary to completely detonate the T. N. T.

These results, indicating the effect of compression on the sensitiveness of T. N. T. to detonation, were confirmed by the results of tests on two other samples of T. N. T., but it should be noted that in the three samples there was an appreciable difference as to sensitiveness to detonation with the same priming composition under like conditions of pressure. All of the three samples of T. N. T. tested were commercial products melting at approximately 80° to 81° C. and containing approximately the theoretical content of nitrogen for trinitrotoluene (18.50 per cent).

The two other samples of T. N. T. referred to were designated M1789 and M1790, 0.4000 gram of the sample being used in each test. The priming composition was the same as used in the previous tests with sample 227. Tabulated results of the tests follow.

Results of sand tests of two samples of T. N. T. with different charging pressures and weights of priming charge.

[Priming composition (sample M-54), 89.71 per cent of mercury fulminate and 10.29 per cent of potassium chlorate.]

SAMPLE M1789.

Weight of priming composition.	Total weight of sand pulverized finer than 30-mesh by detonator charged under pressure of—					
	400	300	200	100	50	25
Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
0.3000	34.90					
.2900	34.45	34.40	35.09	34.07	34.44	34.12
.2800	[a] 14.30					
.2700			34.07			
.2500			32.07			
.2300			29.60			
.2200			[a] 22.94			
.2100			[a] 15.04			

SAMPLE M1790.

0.3100	33.42	33.64	34.24	32.25	28.75	30.62
.3000	[a] 14.05					
.2900			31.40			
.2700			30.30			
.2500	[a] 11.50		31.20			
.2400			27.85			
.2300			[a] 15.10			

[a] Incomplete detonation of T. N. T.

Although samples M1789 and M1790 showed a decrease in sensitiveness to detonation with increased charging pressure, it will be noted that they exhibited different degrees of sensitiveness under the same conditions. For example, the results of the tests of the three samples show that the minimum weights of the priming com-

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position required to produce complete detonation of the T. N. T. at all pressures of loading from 400 to 25 atmospheres were as follows: For sample 227, 0.2500 gram; for sample M1789, 0.2900 gram; and for sample M1790, 0.3100 gram.

PROPERTIES OF T. N. T. SAMPLES TESTED.

In order to ascertain whether this difference in sensitiveness to detonation was due to differences in purity of the three samples the following tests of the properties of the samples were made:

Results of tests of properties of T. N. T. samples 227, M1789, and M1790.

Sample No.	Melting point.	Moisture.	Nitrogen.	Ash.	Proportion of sample caught on—					Proportion through 200-mesh.
					40-mesh.	60-mesh.	80-mesh.	100-mesh.	200-mesh.	
	°C.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.
227	79 to 80	0.06	18.38	0.05	1.72	5.36	6.80	9.40	70.12	6.60
M1789	80 to 81	.01	18.45 18.48	.04	18.60	19.80	12.78	10.26	30.98	7.58
M1790	80 to 81	.03	18.45 18.35	.07	5.48	23.56	35.88	31.88	3.00	.20

It is evident that the three samples differed mainly as to granulation or crystalline size, the other properties noted in the table showing relatively small variations. Sample 227 was largely fine crystals (between 100-mesh and 200-mesh); sample M1790 contained only a little very fine and very coarse crystals, most of it being of medium granulation (40-mesh to 100-mesh), whereas sample M1789 consisted of a rather uniform mixture of all sizes, including considerable quantities of both very fine and very coarse crystals.

EFFECT OF RECRYSTALLIZATION OF T. N. T. ON ITS SENSITIVENESS TO DETONATION.

Parts of samples M1789 and M1790 were next purified by recrystallization from alcohol, care being taken to obtain as uniformly fine crystals as possible. Reinforced detonators each containing a 0.4000-gram charge of the recrystallized parts of the samples were prepared, the weight of the priming charge and the charging pressure being varied. The results of the tests were as follows:

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Results of sand tests of recrystallized T. N. T., charging pressure and weight of priming charge being varied.

Sample M1789.			Sample M1790.		
Weight of priming charge.[a]	Total weight of sand pulverized finer than 30-mesh by detonator charged under pressure of—		Weight of priming charge.[a]	Total weight of sand pulverized finer than 30-mesh by detonator charged under pressure of—	
	400 atmospheres.	200 atmospheres.		400 atmospheres.	200 atmospheres.
Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
0.2800	34.40	.....	0.2900	31.65	.....
	33.10	.....	.....	30.00	.....
	.....	.....	.....	[b] 14.00	.....
.2700	[b] 12.60	.....	.2800	[b] 13.7	.....
.2600	[b] 12.50	.....	.2700	[b] 11.8	.....
.2200	.....	31.30	.2300	.....	32.8
.2100	.....	31.90	.2200	.....	[b] 7.35
.2000	.....	28.75	.....	.....	.....
	.....	[b] 17.30	.....	.....	.....

[a] Part of sample M54, containing 89.71 per cent of mercury fulminate and 10.29 per cent of potassium chlorate.
[b] Incomplete detonation of T. N. T.

If these results are compared with those obtained with the original samples, it may be noted that the minimum priming charge required to completely detonate the original sample of M1789 was 0.2900 gram for a compression of 400 atmospheres, and 0.2300 gram for a compression of 200 atmospheres, whereas the minimum priming charges for the recrystallized sample under like conditions were 0.2800 gram and 0.2100 gram. Similarly, the minimum priming charges required to completely detonate the original sample of M1790 were 0.3100 gram for a compression of 400 atmospheres and 0.2400 gram for a compression of 200 atmospheres, as compared with 0.2900 and 0.2300 gram for the part of the sample that was recrystallized.

It is therefore apparent that although recrystallization appeared to increase the sensitiveness to detonation of both samples, the difference noted between the two original samples still existed after recrystallization.

EFFECT OF SIZE OF CRYSTALS OF T. N. T. ON SENSITIVENESS TO DETONATION.

A quantity of the sample of T. N. T. designated M1789 (see table on p. 52) was sifted through 40-mesh and 200-mesh sieves, and the fractions coarser than 40-mesh and finer than 200-mesh were tested separately to determine whether the difference in crystalline size would affect the sensitiveness to detonation. In these tests, reinforced detonators containing 0.4000-gram charges of the two

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samples of fine and coarse T. N. T., with varying weights of priming charge of 90:10 composition (sample M54, as used in preceding tests), were prepared, and these detonators were tested by the sand test in order to determine the minimum weight of priming charge necessary to completely detonate each of the samples of T. N. T. All of the detonators were loaded with a charging pressure of 200 atmospheres.

The results of the tests follow.

Results of sand tests of fine and coarse crystals of T. N. T. (sample M1789).

Test No.	Weight of sand pulverized finer than 30-mesh by T. N. T. crystals coarser than 40-mesh, with a priming charge of—				Weight of sand pulverized finer than 30-mesh by T. N. T. crystals finer than 200-mesh, with a priming charge of—			
	0.2500 gram.	0.2400 gram.	0.2300 gram.	0.2200 gram.	0.2200 gram.	0.2100 gram.	0.2000 gram.	0.1900 gram.
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
1	34.25	34.25	33.65	[a] 17.55	34.00	32.60	31.35	[a] 21.55
2	.....	.....	29.40	24.50	.....	32.95	[a] 14.80	.....
3	.....	.....	33.00	.....	.....	30.35	.....	.....
4	.....	.....	34.90	.....	.....	31.90	.....	.....
5	.....	.....	34.20	.....	.....	33.80	.....	.....

[a] Incomplete detonation of T. N. T.

The minimum priming charge required to detonate the coarse crystals was established at 0.2300 gram, exactly the same as that found for the original sample of M1789 in the tests tabulated on page 51, whereas that for the fine crystals was established at 0.2100 gram, indicating that the finely crystallized T. N. T. was slightly more sensitive to detonation than the coarse crystals.

It therefore seems probable that the differences in sensitiveness to detonation shown by the three T. N. T. samples 227, M1789, and M1790 may have been due largely to the effect of crystalline size, sample 227, containing the largest proportion of fine crystals, being the most sensitive, and sample M1790, containing the smallest proportion of fine crystals, the least sensitive.

DETONATION TESTS OF SEVERAL NITROCOMPOUNDS.

The following tests were made in the same manner as those just described, reinforced detonators being prepared, each containing a 0.4000-gram charge of the nitrocompound, with varying weights of three different compositions—pure mercury fulminate, and the 90:10 and the 80:20 mixtures of mercury fulminate and potassium chlorate. The charging pressure was 200 atmospheres in every test.

In determining the relative sensitiveness to detonation of these nitrocompounds by establishing the limit charge of priming composition that completely detonated the nitrocompound, it was recognized that some slight, uncontrollable variation in conditions of test

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might exert an influence one way or the other when the weight of priming charge was close to the limit. It was therefore decided to establish the minimum charge limit by a series of five consecutive and exactly similar tests, all of which should indicate the completeness of explosion of the nitrocompound.

T. N. T. REINFORCED DETONATORS.

Tests of T. N. T. reinforced detonators were first made, the results being as follows:

Results of sand tests of T. N. T. reinforced detonators, to determine effect of variations in composition and weight of priming charge.

[Sample of T. N. T. designated M1789; 0.4000 gram used in each test.]

Priming charge.		Weight of sand pulverized finer than 30-mesh with a priming charge of—						
Constituent.	Per cent.	0.3200 gram.	0.3000 gram.	0.2800 gram.	0.2600 gram.	0.2500 gram.	0.2400 gram.	0.2300 gram.
		Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
Mercury fulminate	100	.....	.....	.....	33.00	.....	.....	.....
		.....	.....	.....	31.50	.....	.....	.....
		.....	34.20	34.70	30.00	[a] 13.55	[a] 12.60	.....
		.....	.....	.....	32.70	.....	.....	.....
		.....	.....	.....	32.00	.....	.....	.....
		.....	.....	.....	[b] 31.85	.....	.....	.....
Mercury fulminate Potassium chlorate	90 10	37.55	.....	.....	33.55	34.45	32.95	.....
		38.00	.....	.....	34.05	34.67	.....	.....
		37.60	.....	.....	34.35	34.07	[a] 13.20	[a] 13.90
		37.85	.....	.....	34.42	35.07	.....	.....
		37.35	.....	.....	34.70	33.80	.....	.....
		[b] 37.67	.....	.....	[b] 34.21	[b] 34.51	.....	.....
Mercury fulminate Potassium chlorate	80 20	.....	.....	.....	.....	.....	34.40	.....
		.....	.....	.....	.....	.....	34.60	[a] 16.80
		.....	.....	.....	.....	.....	34.60	.....
		.....	.....	.....	.....	.....	33.80	.....
		.....	.....	.....	.....	.....	34.85	.....
	.....	.....	.....	.....	.....	.....	[b] 34.45	.....

[a] Incomplete detonation of T. N. T. [b] Average of 5 tests.

The tests established that the minimum priming charges effecting complete detonation of the T. N. T. were as follows: Pure mercury fulminate, 0.2600 gram; 90:10 composition, 0.2500 gram; 80:20 composition, 0.2400 gram.

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TESTS OF T. N. A. REINFORCED DETONATORS.

T. N. A. detonators were next tested, the results being tabulated below:

Results of sand tests of T. N. A. reinforced detonators, to determine effect of variations in composition and weight of priming charge.

[Sample of T. N. A. designated 228; nitrogen, 26.49 per cent; 0.4000 gram used in each test.]

Priming charge.		Weight of sand pulverized finer than 30-mesh with a charge of—									
Constituent.	Per cent.	0.3200 gram.	0.2500 gram.	0.2300 gram.	0.2100 gram.	0.2000 gram.	0.1900 gram.	0.1800 gram.	0.1700 gram.	0.1600 gram.	0.1500 gram.
		Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
Mercury fulminate	100	.....	34.40	35.20	33.80	32.30	35.50	[a] 4.1	.....	.....	.....
		.....	.....	.....	33.00	32.15	26.80	[a] 3.5	.....	.....	.....
		.....	.....	.....	36.37	30.90	[a] 5.20	.....	.....	.....	.....
		.....	.....	.....	.....	35.60	[a] 4.20	.....	.....	.....	.....
		.....	.....	.....	.....	31.90	.....	.....	.....	.....	.....
		.....	.....	.....	.....	[b]32.57	.....	.....	.....	.....	.....
Mercury fulminate	90	38.80	.....	.....	.....	36.75	.....	.....	33.70	35.22	32.00
Potassium chlorate	10	38.20	.....	.....	.....	.....	.....	.....	35.70	31.30	[a] 4.5
		38.35	.....	.....	.....	.....	.....	.....	32.50	32.50	.....
		38.90	.....	.....	.....	.....	.....	.....	32.50	[a] 5.10	.....
		39.00	.....	.....	.....	.....	.....	.....	36.40	.....	.....
		[b]38.65	.....	.....	.....	.....	.....	.....	[b]34.16	.....	.....
Mercury fulminate	80	.....	.....	.....	.....	.....	.....	.....	35.35	[a] 6.90	[a] 3.3
Potassium chlorate	20	.....	.....	.....	.....	.....	.....	.....	31.40	.....	.....
		.....	.....	.....	.....	.....	.....	.....	34.00	.....	.....
		.....	.....	.....	.....	.....	.....	.....	35.90	.....	.....
		.....	.....	.....	.....	.....	.....	.....	34.85	.....	.....
		.....	.....	.....	.....	.....	.....	.....	[b]34.30	.....	.....

[a] Incomplete detonation of T. N. A. [b] Average of 5 tests.

The tests established that the minimum priming charges effecting complete detonation of the T. N. A. were as follows: Pure mercury fulminate, 0.2000 gram; 90:10 composition, 0.1700 gram; 80:20 composition, 0.1700 gram.

PICRIC ACID REINFORCED DETONATORS.

Tests of picric acid reinforced detonators were also made, with results as follows:

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Results of sand tests of picric acid reinforced detonators to determine effects of variations in composition and weight of priming charge.

[Picric acid, chemically pure; 0.4000 gram used in each test.]

Priming charge.		Weight of sand pulverized finer than 30-mesh with a priming charge of—								
Constituent.	Per cent.	0.3200 gram.	0.2500 gram.	0.2400 gram.	0.2300 gram.	0.2200 gram.	0.2100 gram.	0.2000 gram.	0.1900 gram.	0.1800 gram.
		Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
		.....	33.25	33.20	.....	.....	.....	.....	.....	.....
		.....	33.30	[a] 18.00	.....	.....	.....	.....	.....	.....
		.....	34.95	.....	.....	.....	.....	.....	.....	.....
Mercury fulminate	100	.....	32.80	.....	.....	.....	.....	.....	.....	.....
		.....	32.70	.....	.....	.....	.....	.....	.....	.....
		.....	[b] 33.40	.....	.....	.....	.....	.....	.....	.....
		38.40	.....	.....	35.20	33.00	.....	.....	.....	.....
		38.15	.....	.....	34.20	[a] 21.90	.....	.....	.....	.....
Mercury fulminate	90	38.45	.....	.....	33.50	.....	.....	.....	.....	.....
Potassium chlorate	10	37.75	.....	.....	33.70	.....	.....	.....	.....	.....
		38.15	.....	.....	33.90	.....	.....	.....	.....	.....
		[b] 38.18	.....	.....	[b] 34.10	.....	.....	.....	.....	.....
		.....	.....	.....	35.35	30.25	[a] 28.0	[a] 28.9	[a] 21.1	[a] 12.5
		.....	.....	.....	35.70	32.65	.....	30.6	.....	.....
Mercury fulminate	80	.....	.....	.....	35.60	34.35	.....	.....	.....	.....
Potassium chlorate	20	.....	.....	.....	35.95	34.60	.....	.....	.....	.....
		.....	.....	.....	35.10	34.45	.....	.....	.....	.....
		.....	.....	.....	[b] 35.54	[b] 33.26	.....	.....	.....	.....

[a] Incomplete detonation of picric acid. [b] Average of five tests.

The tests established that the minimum priming charges effecting complete detonation of the picric acid were as follows: Pure mercury fulminate, 0.2500 gram; 90:10 composition, 0.2300 gram; 80:20 composition, 0.2200 gram.

TETRYL REINFORCED DETONATORS.

Tetryl reinforced detonators were also tested. The results are presented in the following tabulation:

Results of sand tests of tetryl reinforced detonators to determine effect of variation in weight and composition of priming charge.

[Sample of tetryl designated 197-*a*; 0.4000 gram used in each test.]

Priming charge.		Weight of sand pulverized finer than 30-mesh with a priming charge of—					
Constituent.	Per cent.	0.3200 gram.	0.2400 gram.	0.2300 gram.	0.2200 gram.	0.2100 gram.	0.2000 gram.
		Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
		.....	34.40	[a] 7.65	32.55	[a] 9.00	[a] 3.4
		.....	35.50	.....	31.75	.....	.....
		36.00	34.35	.....	32.85	.....	.....
Mercury fulminate	100	.....	34.55	.....	[a] 6.80	.....	.....
		.....	34.70	.....	[a] 6.80	.....	.....
		.....	[b] 34.70	.....	.....	.....	.....
Mercury fulminate	90	37.75	.....	.....	.....	.....	.....
Potassium chlorate	10						

[a] Incomplete detonation of tetryl. [b] Average of five tests.

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The tests established that the minimum priming charge effecting complete detonation of the tetryl was 0.2400 gram of pure mercury fulminate.

As the quantity of tetryl on hand was small, the tests with the 90:10 and 80:20 priming compositions could not be completed.

SUMMARY OF RESULTS OF DETONATION TESTS.

The detonation tests showed conclusively that, for the samples of nitrocompounds studied, and under the conditions of the tests, the mixtures of mercury fulminate with potassium chlorate were more efficient detonating materials than the pure mercury fulminate, and that the mixture containing 20 per cent of chlorate was slightly more efficient than that containing 10 per cent of chlorate, the relative detonating efficiency being determined by the minimum weights of priming composition that would completely detonate the nitrocompounds.

These results confirm in every way those obtained without the extra confinement afforded in the reinforced detonators (see table on page 46), and also further substantiate the conclusions drawn from the results of the sand tests of the three priming compositions presented on page 43.

The tests showed also that the additional confinement afforded in the reinforced detonators resulted in an appreciable lowering of the minimum weight of a given priming composition required to detonate a given nitrocompound. For example, in the ordinary detonator, not reinforced, 1 gram of 80:20 composition failed to detonate 0.4000 gram of T. N. T., (see p. 47), whereas in the reinforced detonator 0.2400 gram of the same 80:20 priming composition completely detonated 0.4000 gram of T. N. T. In the tests of T. N. A., 0.3125 gram of 80:20 composition was required to effect detonation in the ordinary detonator, whereas 0.1700 gram of the same priming composition produced complete detonation in the reinforced detonator.

The sand tests of these reinforced detonators showed results only slightly lower than those obtained with the somewhat larger weights of priming charge in the tests represented in the table on page 46, the difference being what would be expected from the reduction in the weight of total charge.

It is further noted that the weight of sand pulverized was almost uniformly greater when the chlorate priming compositions were used than when the priming charge was pure fulminate, even though the weight of pure fulminate was greater than that of the chlorate mixture.

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A summary of the results shown in the four tables on pages 55 to 57 follows:

Summary of results of tests to determine minimum priming charges effecting complete detonation of nitrocompounds in reinforced detonators loaded at pressure of 200 atmospheres.

Nitrocompound.		Priming charge.			
Designation.	Weight.	Composition.		Minimum weight for complete detonation.	Weight of sand finer than 30-mesh.
		Mercury fulminate.	Potassium chlorate.		
	Grams.	*Per cent.*	*Per cent.*	*Grams.*	*Grams.*
T. N. T. sample M1789	0.4000	100	.....	0.2600	31.85
Do	.4000	90	10	.2500	34.51
Do	.4000	80	20	.2400	34.45
T. N. A. sample 228	.4000	100	.....	.2000	32.57
Do	.4000	90	10	.1700	34.16
Do	.4000	80	20	.1700	34.30
Picric acid (chemically pure)	.4000	100	.....	.2500	33.40
Do	.4000	90	10	.2300	34.10
Do	.4000	80	20	.2200	33.26
Tetryl sample 197–*a*	.4000	100	.....	.2400	34.70
Do	.4000	90	10	(*a*)	.....
Do	.4000	80	20	(*a*)	.....

a Tests not made because of insufficient supply of tetryl.

It is also of interest to note that the total strength shown by equal weights of each of the four nitrocompounds was nearly the same when equal weights of the same priming composition were used and the charges were subjected to similar pressures. Thus, with 0.3200 gram of 90:10 priming composition, a charge of nitrocompound of 0.4000 gram, and a loading pressure 200 atmospheres, the weights of sand pulverized finer than 30-mesh were as follows: Trinitrotoluene detonator, 37.67 grams; tetranitroaniline detonator, 38.65 grams; tetranitromethylaniline detonator, 37.75 grams; picric acid detonator, 38.18 grams. Each of these results is the average of five tests as noted in the tabulated results, and the total variation in the average results is no greater than the variation in a series of five tests with the same nitrocompound.

COMPARISON OF COMMERCIAL T. N. T. REINFORCED DETONATORS WITH COMMERCIAL FULMINATE DETONATORS.

Four samples of T. N. T. reinforced detonators were tested by means of the sand test to determine their "strength" in comparison with the ordinary type of detonators containing 90 per cent of mercury fulminate and 10 per cent of potassium chlorate. The commercial T. N. T. detonators used were designated as grades 5, 6, 7, and 8, and were manufactured to be equivalent to the corresponding grades of fulminate detonators.

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COMPOSITION AND WEIGHT OF CHARGE OF T. N. T. DETONATORS.

The weight and the results of analysis of charge in each of the four samples were as follows, as shown by averages on two to three detonators:

Weight and analysis of charge of each of four samples of commercial T. N. T. reinforced detonators.

Item.	Sample (grade) No.—			
	5	6	7	8
Weight of total charge, grams	0.6133	0.7035	1.1078	1.2498
Weight of T. N. T. detonating charge, grams	.3008	.3872	.7940	.9113
Weight of priming charge, grams	.3125	.3163	.3138	.3377
Analysis of priming charge:				
Mercury fulminate, per cent	89.20	89.25	89.51	89.73
Potassium chlorate, per cent	10.80	10.75	10.49	10.27

RESULTS OF SAND TESTS.

Four detonators of each of these grades were tested by the sand test, with a view to comparing the results with the average results of tests of the commercial fulminate detonators of the same grades, as presented in the summary on page 31. The results of the tests are presented below, together with the averages mentioned:

Results of sand tests of four reinforced T. N. T. detonators and of four ordinary commercial detonators.

Grade of detonator.	Average weight of sand pulverized finer than 30-mesh by—		Average weight of total charge of—	
	T. N. T. detonators.	Mercury fulminate detonators (90:10 composition).	T. N. T. detonators.	Mercury fulminate detonators (90:10 composition).
	Grams.	*Grams.*	*Grams.*	*Grams.*
No. 5	31.29	30.90	0.6133	0.7220
No. 6	35.37	36.61	.7035	.9842
No. 7	50.99	47.16	1.1078	1.4377
No. 8	56.32	54.53	1.2498	1.8345

These results justify the conclusion that the four samples of commercial T. N. T. detonators were equivalent in "strength" to the average fulminate detonators of the same grades.

EFFECT OF MOIST ATMOSPHERE.

In order to determine the effect of continued exposure to moist atmosphere, samples of both T. N. T. reinforced detonators and of mercury fulminate detonators, previously weighed, were exposed in a humidor to an atmosphere saturated with moisture at laboratory temperature. At intervals one or more of the detonators of each

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kind and grade were removed from the humidor, weighed, and subjected to the sand test.

Both the T. N. T. reinforced detonators and the fulminate detonators gradually increased in weight, owing to absorption of moisture. The sand tests showed that as the amount of moisture absorbed increased, a gradual decrease resulted in the "strength" of the T. N. T. detonators of all grades, whereas the "strength" of the fulminate detonators, as indicated by the sand tests, remained practically unchanged.

The following tabulation for the No. 5 T. N. T. detonators is characteristic of the results obtained with all of the other grades of T. N. T. detonators.

Results of sand tests of No. 5 T. N. T. detonators after exposure to moist atmosphere.[a]

Test No.	Time detonator was in humidor.	Average increase in weight.	Total weight of sand pulverized finer than 30-mesh in sand test.
	Days.	*Grams.*	*Grams.*
1	7	0.0011	(b)
2	14	.0015	28.40 25.69
3	21	.0039	[c] 10.20 [c] 15.00
4	28	.0061	[c] 8.15 [c] 7.72
5	29	.0066	[c] 5.50
6	66	.0082	[c] 4.90

[a] Before exposure the average quantity of sand pulverized finer than 30-mesh in sand test was 31.29 grams.
[b] No sand test made because it was thought that the slight absorption would not affect the results.
[c] Incomplete detonation.

After exposure in the humidor for 29 days, two of these detonators were removed, dried over sulphuric acid in a vacuum desiccator for one and two days, weighed, and subjected to the sand test. The detonator dried one day weighed only 0.0004 gram more than its original weight, and in the sand test pulverized 32.41 grams of sand finer than 30-mesh; the one dried two days returned exactly to its original weight and gave a sand-test value of 32.86 grams.

Similar results were obtained on the T. N. T. detonators of No. 6, No. 7, and No. 8 grades, showing conclusively that although exposure to moist atmosphere for several weeks may cause a total loss of detonating efficiency, these detonators regain their original strength on removal of the absorbed moisture.

No. 7 fulminate detonators were also subjected to the sand test after exposure to a moist atmosphere. The average weight of charge was 1.4554 grams, containing 89.71 per cent of mercury fulminate and 10.29 per cent of potassium chlorate. The average sand-test value before exposure was 46.96 grams. The results of the tests follow.

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Results of sand tests of No. 7 fulminate detonators after exposure to moist atmosphere.

Test No.	Time detonator was in humidor.	Average increase in weight.	Total weight of sand pulverized finer than 30-mesh in sand test.
	Days.	*Grams.*	*Grams.*
1	7	0.0028	47.30
2	14	.0044	48.36
3	21	.0048	47.86
4	28	.0086	47.20
5	38	.0104	47.60
6	52	.0110	46.50

DISCUSSION OF TESTS.

The tabulated results show that no appreciable change in strength of the No. 7 fulminate detonators was effected by the absorption of an amount of moisture equal to approximately 0.75 per cent of the original weight of charge. Under these same conditions the T. N. T. detonators became entirely useless, seemingly because the detonating efficiency of the fulminate priming charge had become diminished by the absorption of moisture. The experiments previously described showed that under certain conditions the minimum priming charge of 90:10 composition that can produce complete detonation of T. N. T. may be as much as 0.3100 gram. Priming charges weighing only 0.3125 to 0.3377 gram (see table, p. 60) in commercial T. N. T. detonators are therefore only slightly in excess of the minimum weight necessary for producing complete detonation of the T. N. T. If, then, the efficiency of the priming charge is only slightly diminished by such cause as the absorption of a small amount of moisture, the complete detonation of the T. N. T. does not result on explosion of the priming charge. The ordinary fulminate detonators were not affected by such exposure to moisture, probably for the sole reason that the weight of fulminate composition in them was in a proportion much greater than the weight of moisture absorbed. Longer exposure would no doubt have caused the same deterioration as was noted in the T. N. T. detonators.

The fact, however, that the T. N. T. detonators became entirely unserviceable after storage for as short a period as three weeks under conditions that might exist in a damp storage magazine or during a protracted period of wet weather justifies the conclusion that the use of a priming charge too close to the minimum limit is not advisable.

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RELATION OF POSITION OF DETONATOR TO RESULT OF SAND TEST.

In connection with the sand tests effort was made to determine the effect of failure to arrange the detonator in the exact center of the mass of 100 grams of sand in the bomb used in the tests.

As noted on page 14, it was found that if 40 grams of the sand was placed in the bomb, the detonator held in position on top of this layer, and the remaining 60 grams poured around it, the charge in the detonator was approximately in the center of the sand. This procedure was followed in all tests described in this bulletin, except as otherwise noted. In the tests discussed below the weight of the first part of sand was successively varied from 30 grams to larger quantities up to 50 grams, so that in the different tests the detonator was placed at points considerably below or above the central point of the sand.

Results of tests of detonators placed at different points within the bomb.

Designation of detonator.....	178.			M1588.			M54.		
Grade of detonator.....	No. 5.			No. 6.			No. 7.		
Weight of sand below detonator, grams.....	30	40	50	30	40	50	30	40	50
Weight of sand pulverized finer than 30-mesh, grams.....	28.83	28.04	29.64	36.75	36.00	38.51	49.75	48.83	47.86

The results of these tests of three samples of detonators in different positions in the sand show such slight variations that it can be concluded that failure to adjust the detonator in the exact center of the sand will not appreciably affect the weight of sand pulverized by the explosion of the detonator.

STANDARDIZATION OF TESTING METHOD.

The apparatus for conducting the sand test in the laboratory of the Bureau of Mines can easily be duplicated by persons desiring to make tests of detonators supplied them by the manufacturers, and if the "standard sand" described on page 12 is used the results obtained should be entirely comparable with the results discussed in this bulletin.

If there are any deviations from the size or shape of the bomb or from the grade of sand described, it would be necessary to standardize the method to apply to the particular apparatus used, in order to determine the grade of a given detonator or to compare the results of the tests with those discussed herein.

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CONCLUSIONS.

The results obtained in the tests described in this report justify the conclusion that the sand test provides an exact means of grading commercial detonators. As regards each of the fulminate compositions tested, the value established by the sand test has been shown to be a definite function of the weight of charge. It has also been demonstrated that the weight of charge of a given composition in a detonator may be closely estimated from the quantity of sand pulverized in the sand test of the detonator.

The relative efficiencies of the various fulminate compositions tested, as indicated by the quantity of sand crushed by each when subjected to the sand test, have been shown to be comparable with their relative efficiencies in causing complete detonation of nitrosubstitution compounds of varying degrees of sensitiveness to detonation.

If the efficiency of a detonator in crushing sand and in causing the detonation of nitrosubstitution compounds may be taken as a measure of its efficiency in practical work in detonating blasting explosives, such as the nitroglycerin dynamites, the sand test fulfills every requirement of a practical test of the "strength" of commercial detonators.

So far as the authors are aware no practical test based on relative ability to bring about complete detonation and develop the maximum energy of nitroglycerin explosives, and yet subject to such influences as normal variations in density and uniformity of composition of the explosives, thus permitting accurate comparison of detonators, has yet been devised, but it is believed that the results of such a test would confirm those of the sand test.

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PUBLICATIONS ON EXPLOSIVES FOR MINING AND ACCIDENTS THEREFROM.

A limited supply of the following publications of the Bureau of Mines is temporarily available for free distribution. Requests for all publications can not be granted, and applicants should limit their selection to publications that may be of especial interest to them. Requests for publications should be addressed to the Director, Bureau of Mines, Washington, D. C.

BULLETIN 15. Investigations of explosives used in coal mines, by Clarence Hall, W. O. Snelling, and S. P. Howell, with a chapter on the natural gas used at Pittsburgh, by G. A. Burrell, and an introduction by C. E. Munroe. 1911. 197 pp., 7 pls., 5 figs.

BULLETIN 17. A primer on explosives for coal miners, by C. E. Munroe and Clarence Hall. 61 pp., 10 pls., 12 figs. Reprint of United States Geological Survey Bulletin 423.

BULLETIN 59. Investigations of detonators and electric detonators, by Clarence Hall and S. P. Howell. 1913. 73 pp., 7 pls., 5 figs.

BULLETIN 66. Tests of permissible explosives, by Clarence Hall and S. P. Howell, 1913. 313 pp., 1 pl., 6 figs.

BULLETIN 69. Coal-mine accidents in the United States and foreign countries, compiled by F. W. Horton. 1913. 102 pp., 3 pls., 40 figs.

BULLETIN 80. A primer on explosives for metal miners and quarrymen, by C. E. Munroe and Clarence Hall. 1915. 125 pp., 15 pls., 17 figs.

TECHNICAL PAPER 6. The rate of burning of fuse as influenced by temperature and pressure, by W. O. Snelling and W. C. Cope. 1912. 28 pp.

TECHNICAL PAPER 7. Investigations of fuse and miners' squibs, by Clarence Hall and S. P. Howell. 1912. 19 pp.

TECHNICAL PAPER 12. The behavior of nitroglycerin when heated, by W. O. Snelling and C. G. Storm. 1912. 14 pp., 1 pl., 2 figs.

TECHNICAL PAPER 17. The effect of stemming on the efficiency of explosives, by W. O. Snelling and Clarence Hall. 1912. 20 pp., 11 figs.

TECHNICAL PAPER 18. Magazines and thaw houses for explosives, by Clarence Hall and S. P. Howell. 1912. 34 pp., 1 pl., 5 figs.

TECHNICAL PAPER 30. Mine-accident prevention at Lake Superior iron mines, by D. E. Woodbridge. 1913. 38 pp., 9 figs.

TECHNICAL PAPER 40. Metal-mine accidents in the United States during the calendar year 1911, compiled by A. H. Fay. 1913. 54 pp.

TECHNICAL PAPER 46. Quarry accidents in the United States during the calendar year 1911, compiled by A. H. Fay. 1913. 32 pp.

TECHNICAL PAPER 48. Coal-mine accidents in the United States, 1896–1912, with monthly statistics for 1912, compiled by F. W. Horton. 1913. 74 pp., 10 figs.

TECHNICAL PAPER 52. Permissible explosives tested prior to March 1, 1913, by Clarence Hall. 1913. 11 pp.

TECHNICAL PAPER 61. Metal-mine accidents in the United States during the calendar year 1912, compiled by A. H. Fay. 1913. 76 pp., 1 fig.

TECHNICAL PAPER 67. Mine signboards, by Edwin Higgins and Edward Steidle. 1913. 15 pp., 1 pl., 4 figs.

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TECHNICAL PAPER 69. Production of explosives in the United States in the calendar year 1912, compiled by A. H. Fay. 8 pp.

TECHNICAL PAPER 71. Permissible explosives tested prior to January 1, 1914, by Clarence Hall. 1914. 12 pp.

TECHNICAL PAPER 92. Quarry accidents in the United States during the calendar year 1913, compiled by A. H. Fay. 1914. 76 pp.

TECHNICAL PAPER 94. Metal-mine accidents in the United States during the calendar year 1913, compiled by A. H. Fay. 1914. 73 pp.

TECHNICAL PAPER 100. Permissible explosives tested prior to March 1, 1915, by S. P. Howell. 1915. 16 pp.

TECHNICAL PAPER 111. Safety in stone quarrying, by Oliver Bowles. 1915. 48 pp., 5 pls., 4 figs.

MINERS' CIRCULAR 7. Use and misuse of explosives in coal mining, by J. J. Rutledge, with a preface by J. A. Holmes. 1913. 52 pp., 8 figs.

MINERS' CIRCULAR 13. Safety in tunneling, by D. W. Brunton and J. A. Davisl 1913. 19 pp.

MINERS' CIRCULAR 19. The prevention of accidents from explosives in meta. mining, by Edwin Higgins. 1914. 16 pp., 11 figs.

MINERS' CIRCULAR 21. What a miner can do to prevent explosions of gas and of coal dust, by G. S. Rice. 1915. 24 pp.

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